Institut für Bahntechnik GmbH

OpenPowerNet

User Manual

Institut für Bahntechnik GmbH
Branch Office Dresden

Document No. OPN/51/1.2.2

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Author	Review	Release
_____	_____	_____
Date Martin Jacob	Date Harald Scheiner	Date Dr. Jörg von Lingen

Revision Record

Issue	Date	Change Reason
1.0	2006-04-10	Created.
1.1	2008-11-24	Reworked.
1.1.0	2009-06-26	Update to OpenPowerNet version 1.1.0
1.2.0	2009-09-22	Adding tutorials and update to version 1.2.0
1.2.1	2010-01-07	Adding chapters 4.2.2, 7.10
1.2.2	2010-05-12	Update versions

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1 Introduction

1.1 Overview

The purpose of this document is to describe the usage of the OpenPowerNet software including the modules ATM and PSC. It explains how to configure, run and analyse simulations. This document corresponds to OpenPowerNet release 1.2.2.

Some of the used package names are brand names registered by companies other than IFB. Please refer to the license descriptions coming with that software packages.

1.2 Versions

OpenPowerNet requires the following versions of associated applications. Additionally the OpenPowerNet software and documentation have their own version.

Applications / Documents	Version
Analysis Tool	0.1.2.1
Installation Instruction	1.2.2
MySQL	5.0.67
MySQL ODBC driver	5.1.5 & 3.51.27
OpenPowerNet	1.2.2
OpenTrack	1.5.5 (2009-11-28)
OPN Database	12
RailML Rolling Stock Schema	1.03.OPN.1

1.3 Acronyms and abbreviations

The following abbreviations are used within this document:

Abbreviation	Description
ATM	Advanced Train Model
CD	Compact Disk
DSN	Data Source Name
GUI	Graphical User Interface
HTML	Hyper Text Markup Language
OCS	Overhead Catenary System
ODBC	Open Database Connection
OPN	OpenPowerNet
PSC	Power Supply Calculation
RailML	Railway Markup Language
RMS	Root Mean Square
TRLPC	Time-Rated Load Periods Curve
XML	Extensible Markup Language

1.4 How to read this Document

This document uses snippets of XML. The XML is highlighted by the following text format code:

```
XML marked in green has to correspond with data in OpenTrack.
XML marked in red is required by OpenPowerNet.
XML marked in light orange is optional.
XML evaluated by OpenPowerNet is marked in bold and may be mixed with the colours above.
The blue attributes are not required by OpenPowerNet but by the corresponding schema and have
no effect on the simulation.
Any other XML is just black.
```

2 Simulation Philosophy

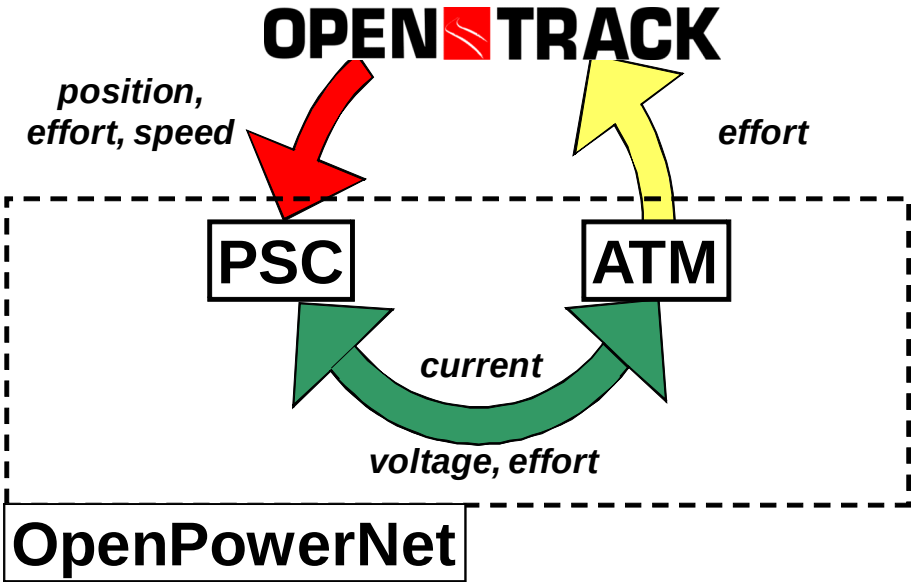


Figure 1 Overview of co-simulation.

The OpenTrack railway operation simulation is realised by a constant time step calculation. OpenTrack and OpenPowerNet work together in a so called co-simulation. This means that both programs are communicating and interacting with each other during the simulation. Each program respective module has a clearly delimited task. OpenTrack simulates the course operation control and the driving dynamics. The OpenPowerNet PSC module simulates voltages of the electrical network in respect of the course current consumption and position. The OpenPowerNet engine simulation module ATM simulates the requested current and achieved effort in respect of the available line voltage at course position.

The sequence of simulation starts in OpenTrack. First a start request is sent to the other modules and some initial tasks are organised. A matrix representing the electrical network is set up and the voltages of the electrical network without load are calculated. After initialisation the first requested tractive or braking effort of a course is sent from OpenTrack to the PSC at time step 0. The line voltage of the course corresponding to course position calculated in the initial phase is sent to ATM where the achieved effort is calculated and returned to OpenTrack. If there is more than one course, the calculation of the other course efforts follows the same principle.

Then the sequence for the time step 1 follows. The first effort request at time step 1 starts the network calculation with all known courses from time step 0. Next the line voltage at course position is forwarded to ATM and the achieved effort is calculated and sent to OpenTrack. All other courses follow the same procedure as course 1 but no network calculation will take place.

In general at the beginning of each time step the voltages of the electrical network with the known course positions and requested efforts of the previous time step are calculated. Iteration between ATM and PSC takes place and is terminated in case each node voltage changes less as a configured threshold, e.g. 1V. ATM calculates the current according to the line voltage simulated by PSC and PSC calculates the line voltage considering the currents used by courses. Each course is handled as a current source in the electrical network.

3 Application structure

OpenPowerNet is divided into three modules for simulation. Each is executable software, see Figure 2. The module “Power Supply Calculation” (`psc.exe`) realises the electrical network calculation, the “Advanced Train Model” (`atm.exe`) is responsible for the engine calculation and the “APserver” (`apserver.exe`) is the communication interface among the OpenPowerNet modules themselves and to OpenTrack.

The configuration of the three modules is done within the Graphical User Interface (GUI). The simulation specific configuration data is stored in XML files and read at the beginning of a simulation.

The GUI is used to control the simulation, to provide access to the analysis tools and to do tasks related to the database. It also provides the PSC Viewer, a tool to create a graphical representation of the electrical network.

The resulting data of a simulation is stored in a database. The visualisation and analysis of simulation results use the data from the database in post processing.

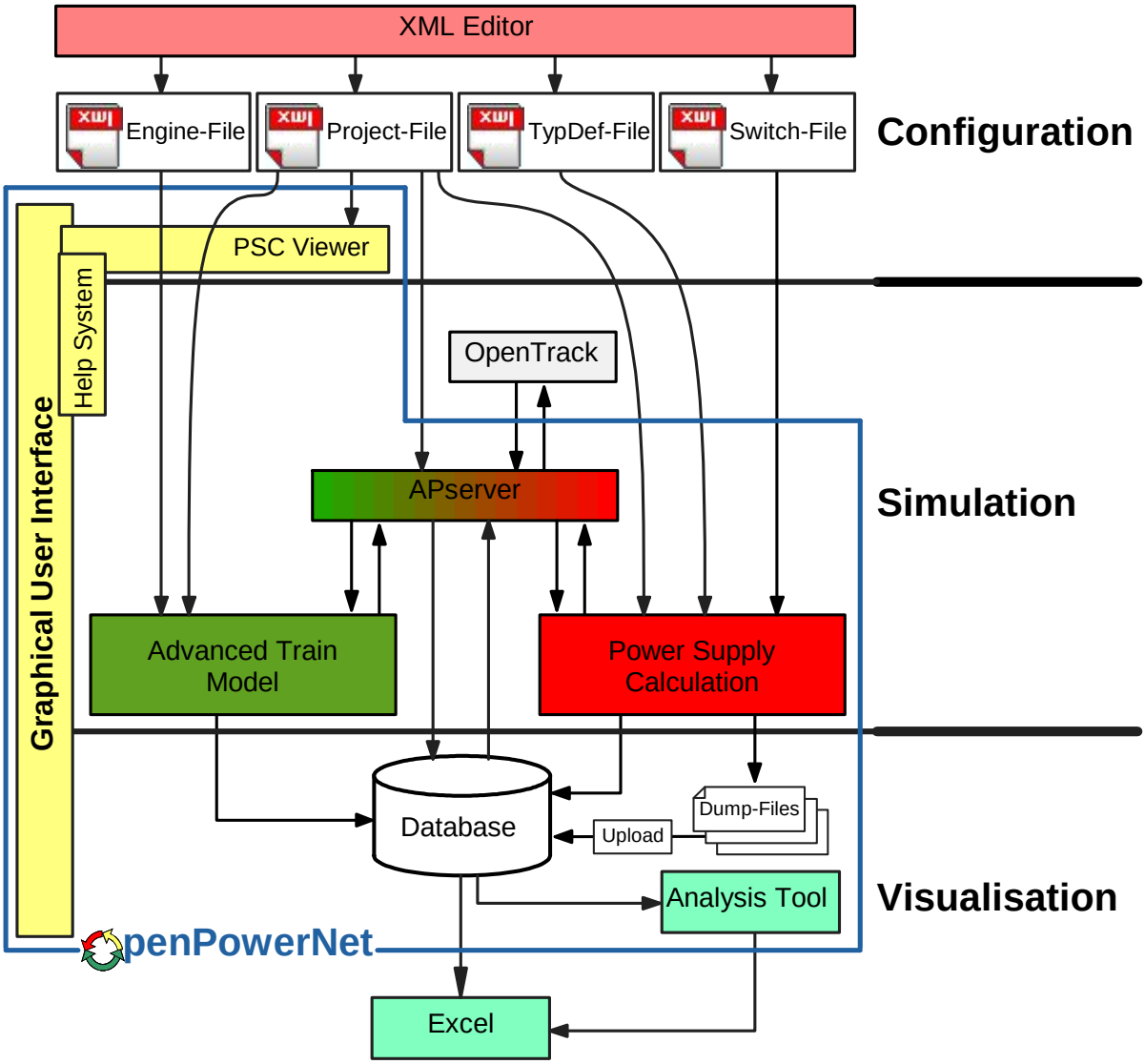


Figure 2 OpenPowerNet workflow and application structure.

3.1 APserver

The APserver is the communication server of OpenPowerNet. This server is the interface to railway simulation programs like OpenTrack. ATM and PSC do not communicate directly with other programs. The APserver manages the iteration of electrical network and engine simulation as well as the actual course status. It is also responsible for writing the course data into the database and for calculating their energy consumption.

3.2 Advanced Train Model

The Advanced Train Model simulates the propulsion system of the engines. The configuration data is stored in the Engine-File, which may act as a library for all simulations similar to the rolling stock depot of OpenTrack, described in chapter 4.2.3.1. The model type and other choices used by the simulation will be set in the Project-File, described in chapter 4.2.3.3.

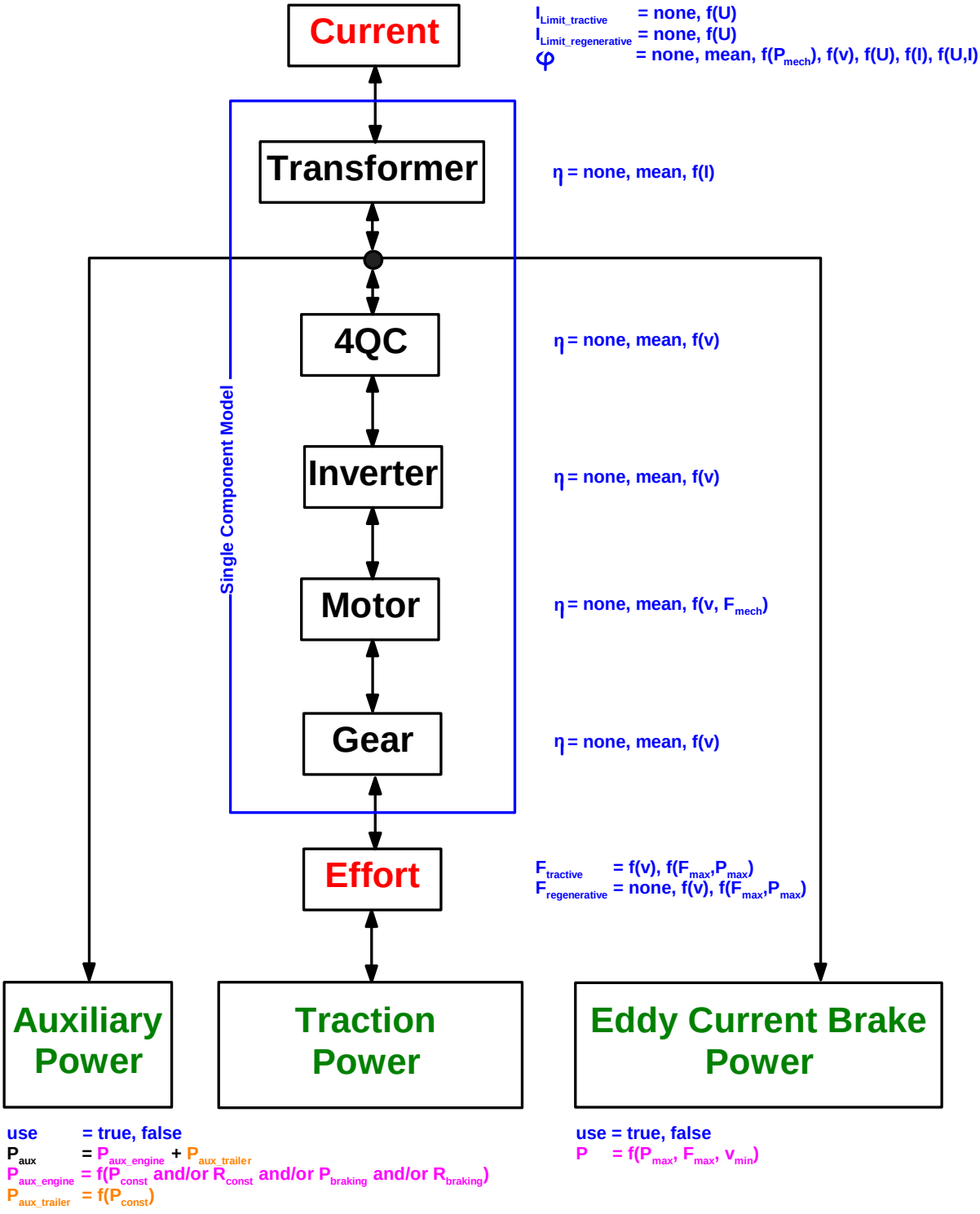
The electrical propulsion system of an engine consists of the following main components:

- Transformer,
- Four quadrant chopper,
- Inverter,
- Motor and
- Gear.

Power consumers are:

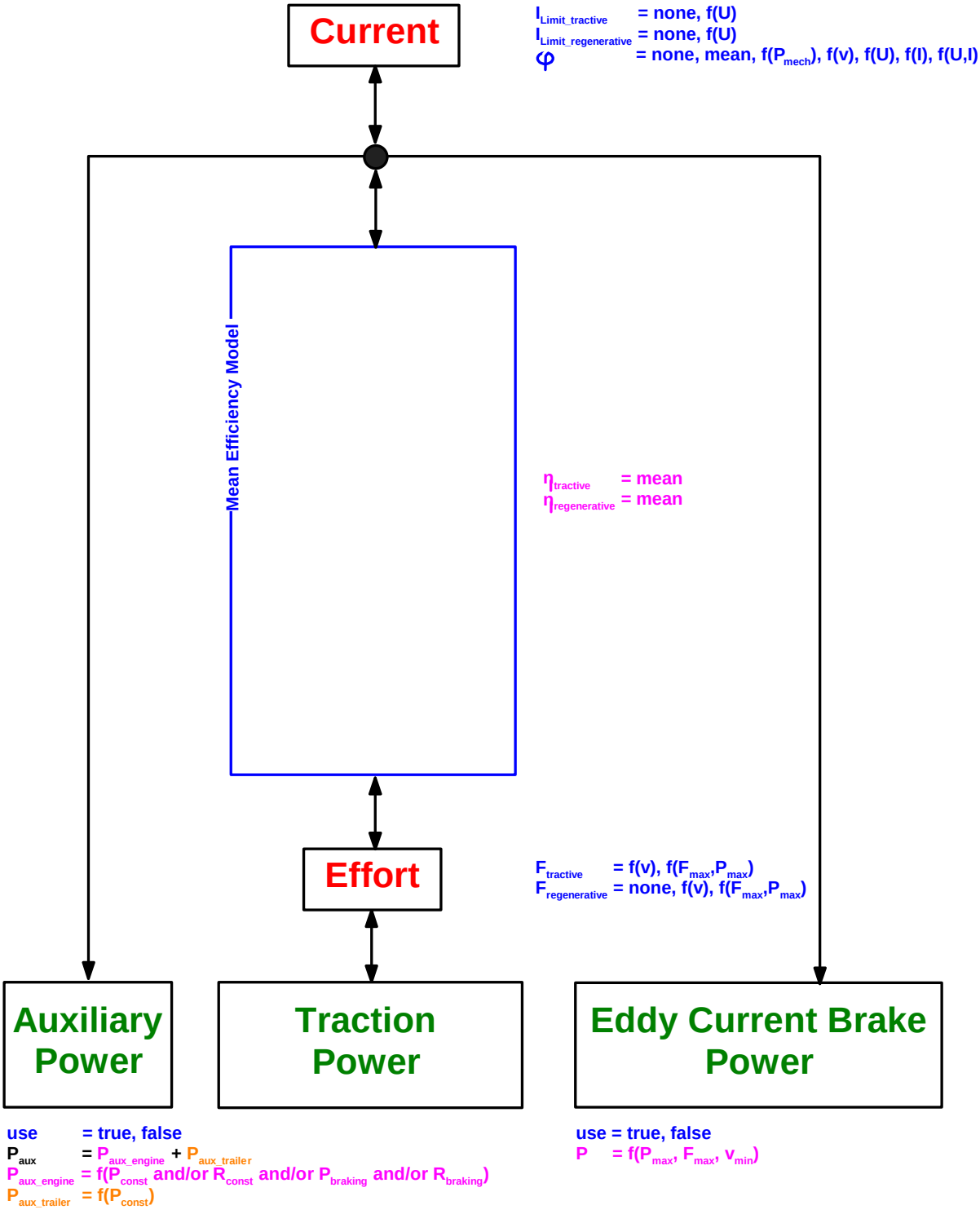
- Auxiliaries of engine and trailers,
- Eddy current brake and
- Traction power.

An engine can be modelled in different ways, in particular as the efficiency depends on the chosen model type, see Figure 3 to Figure 5.



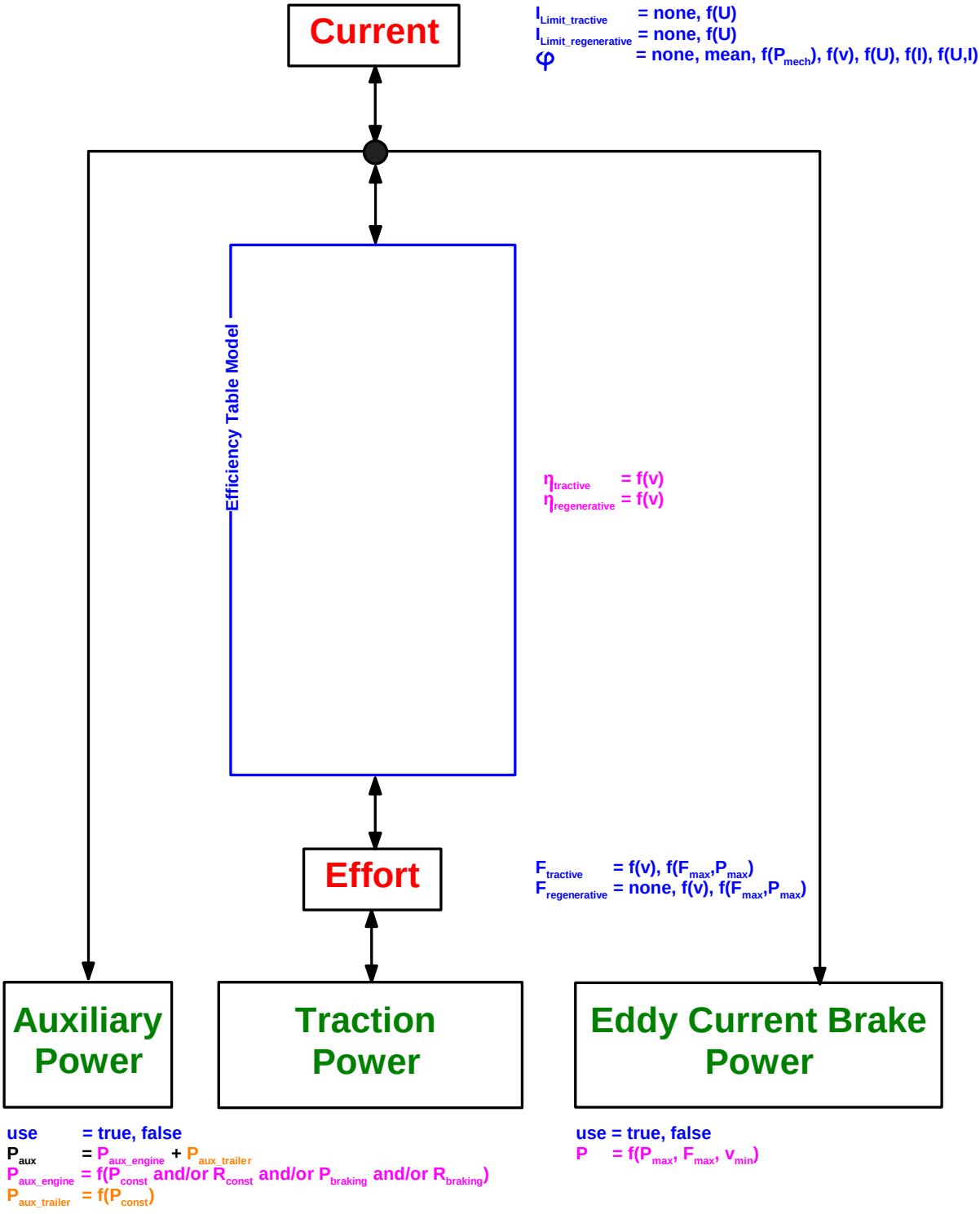
Legend:
configuration options of Project-File
configuration data of Engine-File
configuration data from OpenTrack

Figure 3 Single component engine model with power flow and configuration options.


Current
I Limit_tractive = none, f(U)
I Limit_regenerative = none, f(U)
φ = none, mean, f(P mech), f(v), f(U), f(I), f(U,I)
Mean Efficiency Model
η tractive = mean
η regenerative = mean
Effort
F tractive = f(v), f(F max,P max)
F regenerative = none, f(v), f(F max,P max)
Auxiliary Power
Traction Power
Eddy Current Brake Power
use = true, false
P aux = P aux_engine + P aux_trailer
P aux_engine = f(P const and/or R const and/or P braking and/or R braking)
P aux_trailer = f(P const)
use = true, false
P = f(P max, F max, v min)

Legend:
configuration options of Project-File
configuration data of Engine-File
configuration data from OpenTrack

Figure 4 Mean efficiency engine model with power flow and configuration options.



Legend:
configuration options of Project-File
configuration data of Engine-File
configuration data from OpenTrack

Figure 5 Efficiency table engine model with power flow and configuration options.

Each component of the single component engine model is modelled with an accurate efficiency value with dependencies. If one or more components do not exist in a specific propulsion structure, the efficiency of these components can be set to 100% respectively the model type in the Project-File can be set to none. In this case the component does not have any effect while calculating the total efficiency. In this way engines can be modelled deviating from the model structure of the ATM.

Braking energy is recovered if the demand of the auxiliary and eddy current brake power consumption is exceeded. While braking, OpenPowerNet only calculates the braking effort achieved through energy recovery braking of the propulsion system and eddy current brake, see Figure 6. If the calculated braking effort of the propulsion and eddy current brake is less than the requested effort of the driving simulation, OpenTrack implies that the mechanical brake is able to achieve the remaining brake effort and calculates the driving dynamics using the total requested effort.

A current limitation can be configured for each propulsion system. The tractive current limitation reduces the power consumption and the achievable effort which affects the driving dynamics. The braking current limitation only limits the regenerated energy into the electrical network. Additionally a maximum recovery voltage can be configured that limits the energy output while braking to respect this voltage.

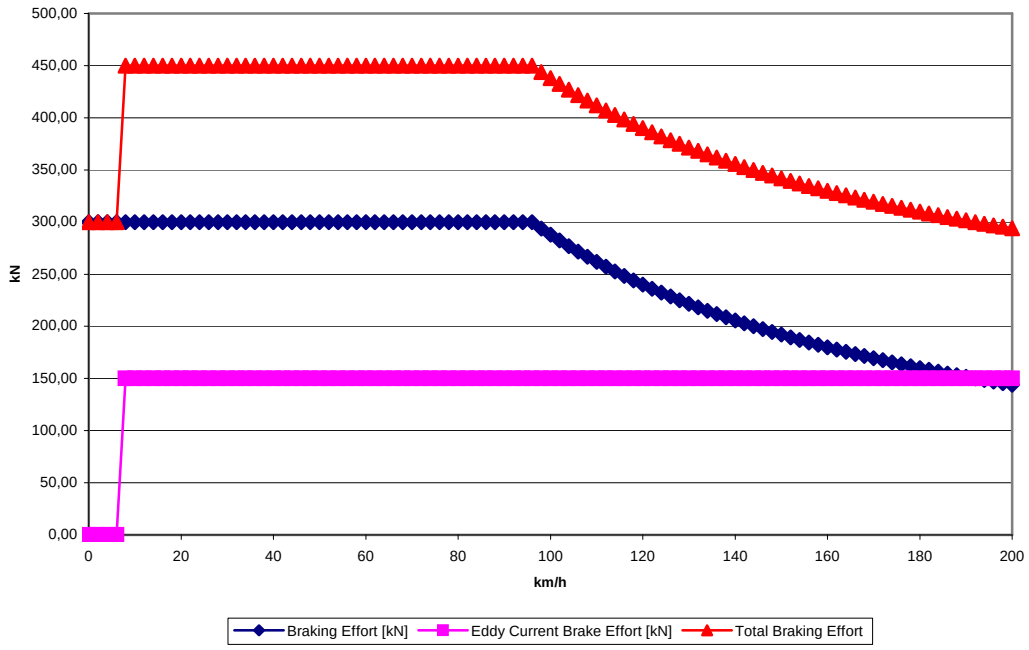


Figure 6 Brake effort calculated with maximum recovery effort, maximum recovery power and eddy current brake.

In case that during braking the recovered energy exceeds the energy consumption of the course the excessive energy is regenerated into the electrical network, see Figure 7.

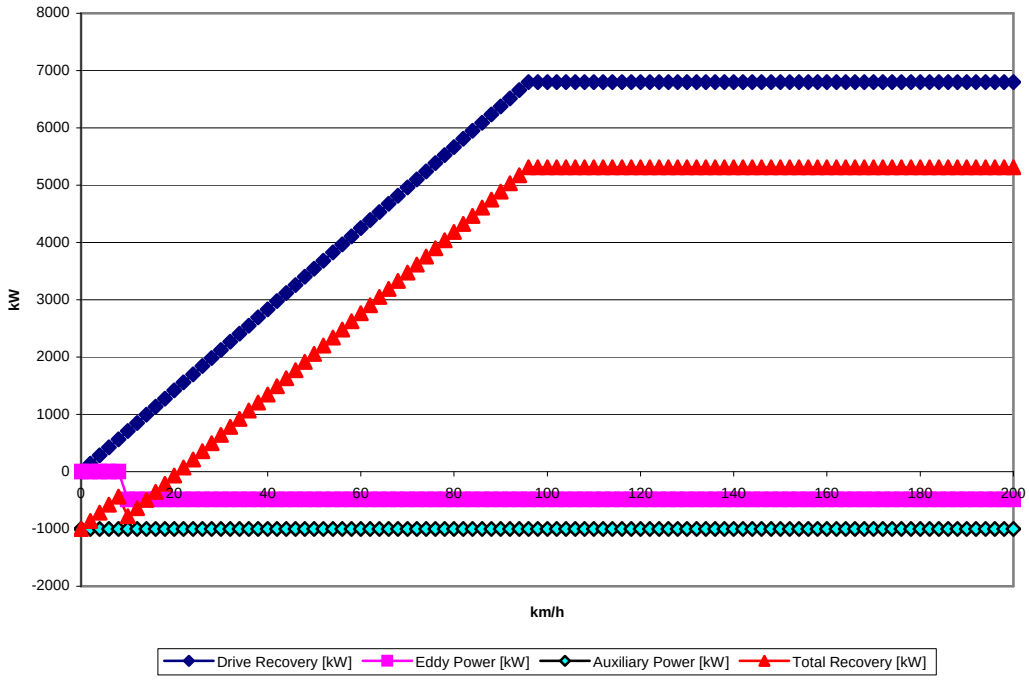


Figure 7 Brake power calculation deducts power used by eddy current brake and auxiliary from recovered power.

3.3 Power Supply Calculation

The PSC calculates the load flows within the electrical network including voltages and currents. The network calculation uses the current required by a course to model this course as a current source. During simulation this current source is inserted at discrete positions while driving along the line. These discrete positions are called slices, see Figure 8.

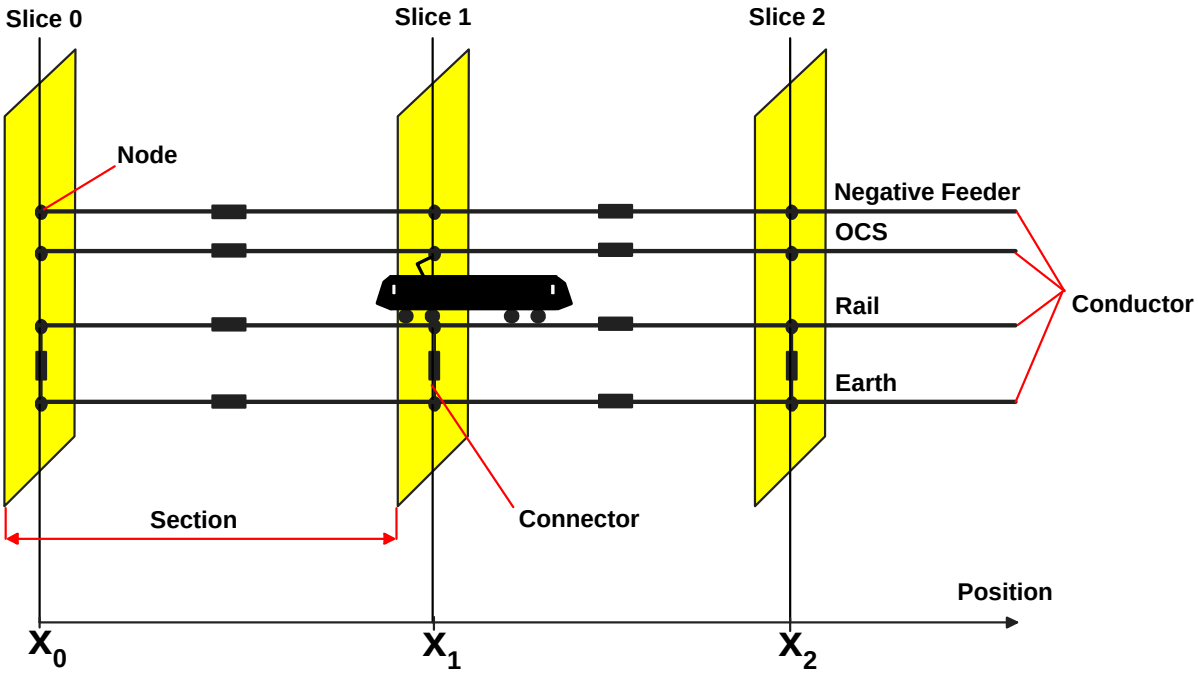


Figure 8 Abstract electrical network model of PSC.

A reasonable slice distance should be about 50m up to 400m depending on the size of the network, the length and number of conductors, and the typical speed of the courses. If the applied slice distance is too large the network model gets inexact and if it is too small the memory demand is significantly larger and the simulation may fail. One possibility of keeping the network size low is to separate the network into several parts if possible for the particular network structure. The structure of these smaller networks can be calculated faster. During simulation all network parts can be used at the same time. Note that the simulation does not have any retroactive effect between the networks!

PSC is designed, but not limited, to calculate 1AC, see Figure 9, as well as the 2AC, see Figure 10, and DC power supply systems, see Figure 11.

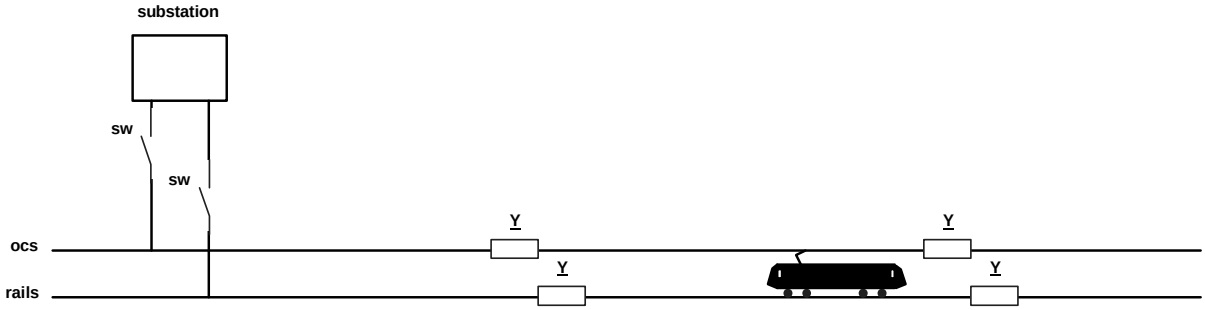


Figure 9 The 1AC power supply system.

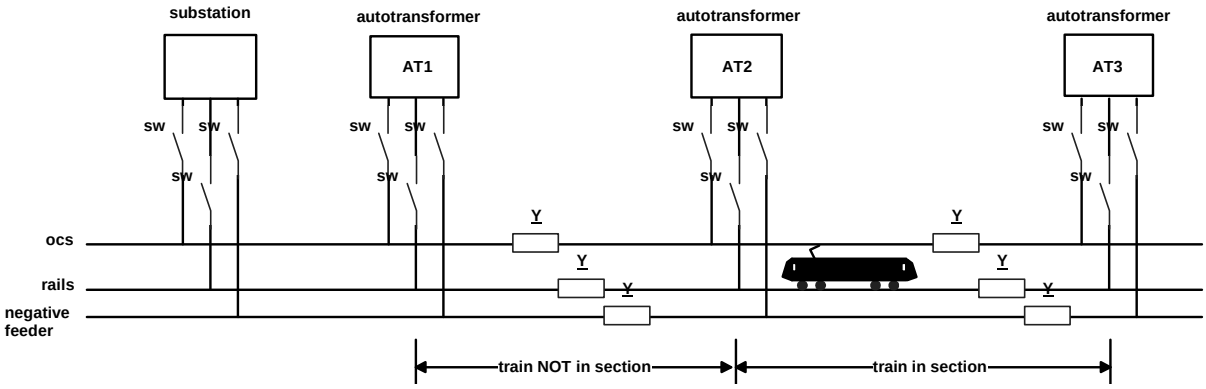


Figure 10 The 2AC power supply system.

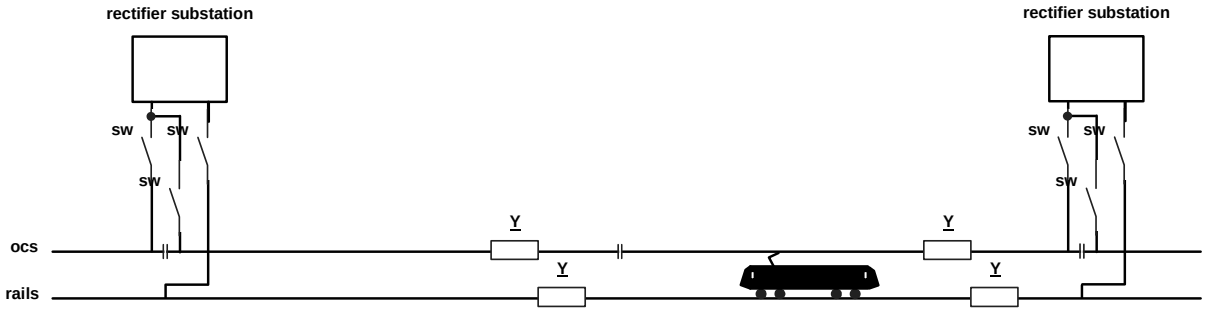


Figure 11 The DC power supply system.

The configuration data of an electrical network (see Figure 12) contains information about:

- Substations including
  - Transformers or rectifiers,
  - Busbars and
  - Switches,
- Conductors like rails, contact wire, messenger wire,
- Connectors connecting the conductors, e.g. the left and right rail,
- Section isolators within a conductor and,
- Switches within conductors and connectors.

The conductors are described with resistance at 20°C, temperature coefficient, temperature, cross section layout and equivalent radius. The impedances of the conductors within a line resulting from electromagnetic coupling are calculated by the PSC using the cross section layout and the equivalent radius of the conductors. Note that all conductors of a line are coupled, but no coupling is calculated between different lines and networks!

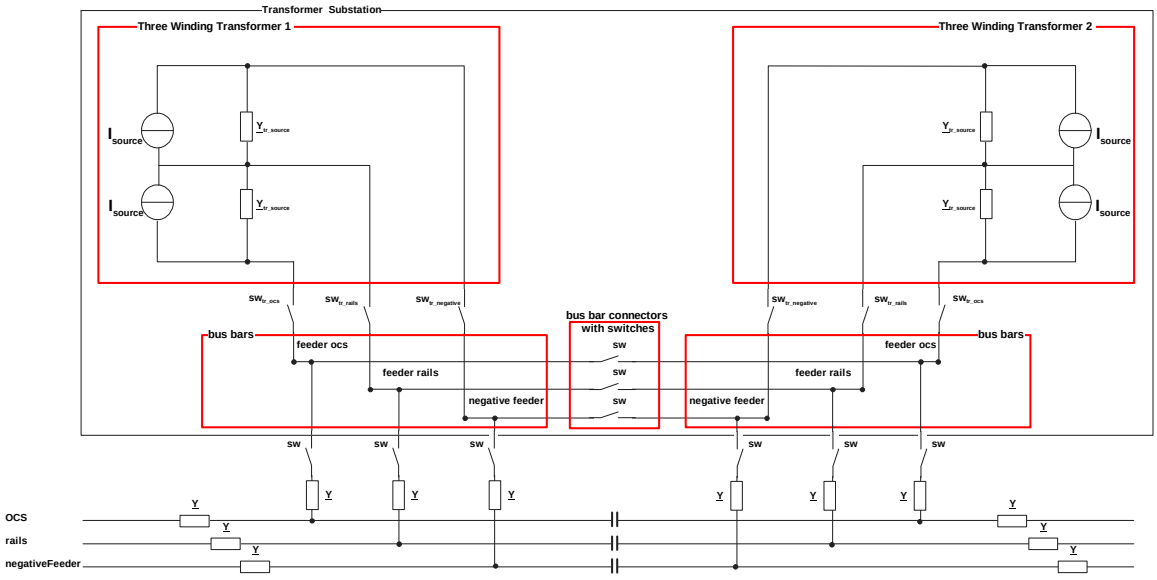


Figure 12 Components of the electrical network.

At simulation start the network structure will be analysed and mapped to a matrix. Each configuration of switch states during the simulation requires a separate matrix. During creation of the matrices there is a peak of memory demand. Afterwards the matrices are compressed and saved to the file system. During simulation these compressed matrices are used for the corresponding simulation time step.

3.4 Graphical User Interface

OpenPowerNet has a Graphical User Interface (GUI) to provide an easy to use interface to the user. It provides a project explorer as a tree with folders and files. The user can start and stop OpenPowerNet, do database tasks, upload dump files and start the analysis tools.

Furthermore the GUI provides the PSC Viewer. The PSC Viewer creates a graphical representation of the electrical network configured in the Project-File.

All descriptions related to the GUI are available in the Help System. The Help System is available by menu `Help > Help Contents` and contains GUI specific help topics.

Via the integrated update system available at menu `Help > Software Updates` … new OpenPowerNet versions and additional plugins can be installed into the GUI. Please see the integrated Help System for detailed information.

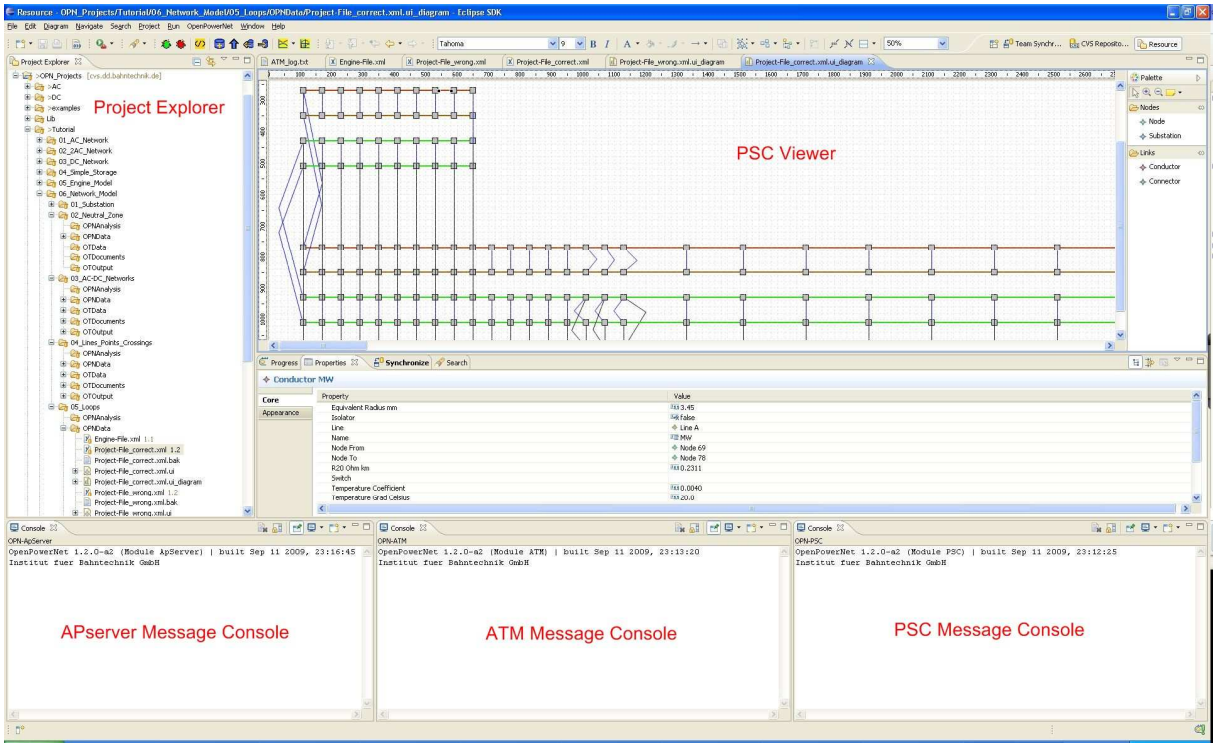


Figure 13 The OpenPowerNet perspective of the GUI.

3.5 Analysis Tool

OpenPowerNet has a comprehensive analysis tool to create Excel diagrams in an easy, standardised and efficient way. This tool provides the automatic analysis and the magnetic field calculation as main functionality. A detailed description is available in chapter 4.5.

3.6 Database

A database is used to store the simulation results for later visualisation and analysis. The detailed database documentation can be found in the Help System under `OpenPowerNet User Guide > Database`.

To speed up the simulation it is possible to write the current of conductors and connectors as well as the voltage of nodes to dump files. After the simulation is finished the user has to upload these dump files to the database using the functionality provided by the GUI.

Note: that the user has to upload the dump files before a new simulation starts!

3.7 Working directory

The folders and files in the working directory are created by OpenPowerNet during simulation. Only the working directory itself needs to be created manually and specified in OpenPowerNet GUI.

Working directory structure:

```
.../OPN_WorkingDir
   +- Project_Name
      +- Network_NetworkName (Containing network matrices and model text
files)
         +- data (Containing the dump files)
            * ...
         * ...
```

4 OpenPowerNet handling

The configuration of the runtime environment usually has to be done once using the GUI, see the Help System for details. The general usage of OpenPowerNet consists of three main tasks: configuration, simulation and visualisation, see Figure 2. First the project files for the electrical network, engines and switch states have to be prepared in correspondence with the operational project files of OpenTrack. This is probably the most extensive job. The second task is running the simulation in co-simulation with OpenTrack. The third task is the visualisation and analysis of the resulting simulation data.

4.1 Configuration of OpenTrack

OpenTrack is the railway operation simulation program. It handles the driving dynamics respecting the track alignment, the train characteristics, the signalling system and the operation program. For the handling of OpenTrack please check the documentation delivered with the program. For inter-process communication it is necessary to set some special configurations in OpenTrack, see Figure 14.

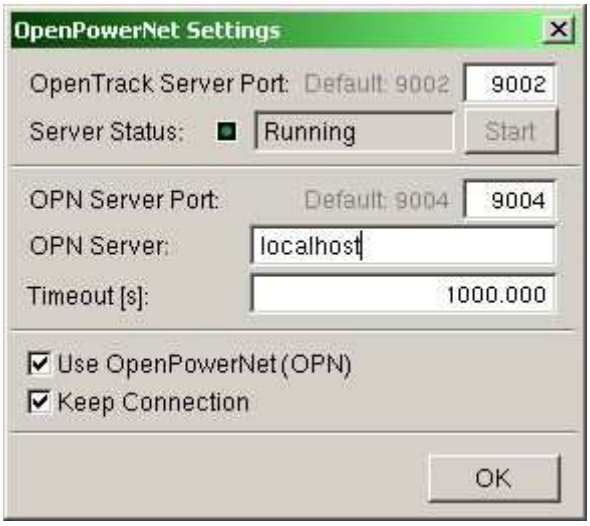


Figure 14 OpenPowerNet configuration dialog in OpenTrack (Menu: Info > OpenPowerNet Settings).

The dialog `OpenPowerNet Settings` is available at menu item `Info` if OpenTrack is started with parameter `OpenTrack.exe -opn`. The following properties have to be set:

- OpenTrack Server Port, 9002 (default),
- OPN Server Port, 9004 (default),
- OPN Host, network name or IP of the computer running OpenPowerNet, localhost (default) for the same computer
- Timeout in seconds, recommended 120,
- Use OpenPowerNet (OPN), checked,
- Keep Connection, checked.

Increase the timeout if connection problems with OpenPowerNet appear during simulations with a large amount of iteration steps, primarily for large networks if engines are allowed to recover energy to the network but the substations must not recover energy to the national power grid.

To be able to run OpenTrack and OpenPowerNet together it is necessary to respect the constraints from chapter 7.1 besides the OpenPowerNet model constraints in chapter 4.2.1.

4.2 Configuration of OpenPowerNet

The configuration of OpenPowerNet is done via the GUI. For details please see the GUI Help System at `OpenPowerNet User Interface User Guide > Preferences`.

XML-Files are used for configuration. Each such file belongs to a schema. A schema describes the structure of an XML-File. The schema is specified in each XML-File in the root element using the attribute `xsi:noNamespaceSchemaLocation`. See the example XML snippet below:

```
<XML-Root-Elemen xsi:noNamespaceSchemaLocation="/the/xml/schema.xsd">
</XML-Root-Elemen>
```

See also the FAQs in chapter 7.8 and 7.9 for an answer of how to get the directory path and which schema to use for which file.

4.2.1 Model constraints

Besides the constraints derived from the OpenTrack model mentioned in chapter 7.1 the model has to fulfil further constraints. Otherwise the simulation is not possible or the results will be wrong!

The following constraints have to be fulfilled:

Auto-, Two Winding- and Three Winding Transformer:

- $0 < relativeShortCircuitVoltage^2 \cdot nomPower^2 - noLoadLosses^2$
- $0 < nomPrimaryVoltage^2 \cdot noLoadCurrent^2 - noLoadLosses^2$

For AC networks the sums of all conductor currents of each section between two slices within a line have to be 0. This means:

- It is not allowed to add connectors parallel to conductors,
- Feeder and return feeder from a substation to the line have to be connected at the same slice and
- Lines shall not be connected in a triangular manner.
- It is not possible to add a switch between the busbar and a rectifier but you can still use a switch in the feeder cable to the line.
- It is not allowed to have more than one contact wire per track.
- It is not allowed to have more than two rails per track.

The occurrence of engines inside the electrical network has to be realistic as each course inside the network consumes at least its auxiliary power. If a course is created at the wrong time step or behaves unrealistic, this has an effect inside the electrical network although the operational simulation may not be affected. All courses that turn up inside the electrical network during the target simulation time have to be modelled, even if they may only stand on a station track (powered on).

If parts of other lines are connected to the main line (e.g. powered by the same substations) and the entire electrical situation shall be analysed, these parts and its course operations also have to be modelled. This can be only omitted, when no load is on the connected parts.

If there are engines with same OpenTrack input data but different electrical parameters for the same catenary system, these engines have to be handled separately. A multi-system traction unit can be handled as a single engine though.

To keep the number of nodes in the electrical network down, special track arrangements should be kept simple. Example: Double track line, junction in track “Up” is located 2 m before junction in track “Down”. In such a case both junctions should get the same position to save one slice.

All configuration data has to use ASCII characters.

4.2.2 Naming Conventions

Names used for model elements need to be unique within a specific scope. The table below gives the overview of naming scopes.

Model element	Unique Name Scope	XML Element	XML Attribute
2 winding transformer	Substation	TwoWindingTransformer	name
3 winding transformer	Substation	TreeWindingTransformer	name
Additional load in substation	none	AdditionalLoad	name
Autotransformer	Substation	Autotransformer	name
Busbar	Substation	OCSBB, RailsBB, NegativeFeederBB	bbName
Conductor	Track	StartPosition	condName
Connector	none	Connector	name
Connector between negative feeder busbars	none	NegativeFeederBBConnector	name
Connector between OCS busbars	none	OCSBBConnector	name
Connector between rails busbars	none	RailsBBConnector	name
Leakage	none	Leakage	name
Line	Network	Line	name
Network	Project	Network	name
Rectifier	Substation	Rectifier	name
Slice	none	ConnectorSlice	name
Storage	none	Storage	name
Substation	Network	Substation	name
Switch	Project	Switch	Name
Engine name	Project	Engine-File: vehicle	vehicleID
		Project-File: Vehicle	engineID

Table 1 The naming conventions of the model elements versus scope.

4.2.3 Project specific configuration

The project specific configuration files describe the engines, the used engine model, the definition of power supply, the electrical network and optionally the switch states of the electrical network. All files are XML files. While it is possible to do basic editing with any text editor it is recommended to use any XML editor like the commercial one “Altova XMLSpy” for convenient configuration. The schemas for validation and assisted creation of the XML files can be found in the sub folder `schemas` of the `de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm` plugin. If the XML files are loaded into the XML editor together with schema files they help creating and understanding the structure of the configuration files and lots of values can be suggested automatically. Please refer to the user manual of your editor for further details on editing XML files.

The project specific files that are used for simulation are configured in the root element of the Project-File. The Project-File and these referenced files are read every time a simulation has started. Hence it is not necessary to restart OpenPowerNet after changing the name or content of a project specific file.

4.2.3.1 Engine-File

This file acts as a library of engines and contains all information for a simulation. It has to correspond with the OpenTrack engine data. The engine ID is used for mapping the engine data between both programs. The XML file observes the RailML Rolling Stock Schema 1.03.OPN.1 provided as file `schemas/rollingstock.xsd`. The schema specification documentation is available in the GUI Help System under `OpenPowerNet User Guide > Engine-File`.

Table 2 to Table 5 list the data processed by ATM, considering the engine models from Figure 3 to Figure 5. The position where the data shall be inserted into the Engine-File is described by X-Path which is similar to a path of the file system. XML-elements can be understood as folders and XML-attributes as files containing the data. A path to an attribute contains an '@' as prefix of the attribute name.

Below is an example Engine-File with one engine equipped with one propulsion system. Note the colour code explained in chapter 1.4!

```
<?xml version="1.0" encoding="UTF-8"?>
<railml xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="D:\Usr\OpenPowerNet-
x.y.z\plugins\de.bahntechnik.dd.opn.bin_1.1.0.b6_200905261507\schemas\rollingstock.xsd">
  <rollingstock rollingstockID="" version="110">
    <vehicles>
      <vehicle length="25" bruttoWeight="75" vehicleID="Engine1" speed="250">
        <engine>
          <propulsion supply="AC 25kV 50Hz" transmission="electric" engine="electric"
power="5560" maxTractEffort="250" totalTractEfficiency="90" totalBrakeEfficiency="90">
            <auxSupply typeStr="all" constPower="100"/>
          </propulsion>
        </engine>
      </vehicle>
    </vehicles>
  </rollingstock>
</railml>
```

item	model type/ choice	X-Path to data from Engine-File (/railml/rollingstock/vehicles/vehicle/…)
engine ID	required	…/@vehicleID
engine type	required	…/engine/propulsion/@engine
transmission	required	…./engine/propulsion/@transmission
supply	required	…./engine/propulsion/@supply
power angle	none	-
	mean	…/engine/propulsion/fourQuadrantChopper/@meanPhi
	curve	.../engine/propulsion/fourQuadrantChopper/phi/valueTable
tractive current limitation	none	-
	curve	…/engine/propulsion/tractiveCurrentLimitation/valueTable
	optional	.../engine/propulsion/@zeroSpeedCurrentLimitation
brake current limitation	none	-
	curve	…/engine/propulsion/brakeCurrentLimitation/valueTable

item	model type/ choice	X-Path to data from Engine-File (/railml/rollingstock/vehicles/vehicle/…)
use auxiliary power	no	-
	yes	…/engine/propulsion/auxSupply/@constPower …/engine/propulsion/auxSupply/@constResistance …/engine/propulsion/auxSupply/@constPowerBraking …/engine/propulsion/auxSupply/@constResistanceBraking **Note:** Auxiliary while braking is only active for engines with recovery braking!
recovery braking	none	-
	max	…/engine/propulsion/@maxBrakePower …/engine/propulsion/@maxBrakeEffort …/engine/propulsion/@maxRecoveryVoltage
	curve	…/engine/propulsion/brakeEffort/valueTable …/engine/propulsion/@maxRecoveryVoltage
tractive effort	max	…/engine/propulsion/@power …/engine/propulsion/@maxTractEffort
	curve	…/engine/propulsion/tractiveEffort/valueTable
eddy current brake	none	-
	max	…/brakes/eddyCurrentBrake/@maxPower …/brakes/eddyCurrentBrake/@maxEffort …/brakes/eddyCurrentBrake/@minSpeed **Note:** Eddy current braking is only active for engines with recovery braking!

Table 2 Common data used by ATM.

item	type/ choice	X-Path to data from Engine-File (/railml/rollingstock/vehicles/vehicle/engine/propulsion …)
transformer	none	-
	mean	…/transformer/@meanEfficiency
	curve	…/transformer/efficiency/valueTable
four quadrant chopper	none	-
	mean	…/fourQuadrantChopper/@meanEfficiency
	curve	…/fourQuadrantChopper/efficiency/valueTable
traction inverter	none	-
	mean	…/tractionInverter/@meanEfficiency
	curve	…/tractionInverter/efficiency/valueTable
motor	none	-
	mean	…/tractionMotor/@meanEfficiency
	curve	…/tractionMotor/efficiency/valueTable
gear	none	-
	mean	…/gear/@meanEfficiency
	curve	…/gear/efficiency/valueTable

Table 3 “Single Component Model” specific data used by ATM.

X-Path to data from Engine-File (/railml/rollingstock/vehicles/vehicle/engine/propulsion …)
…/@totalTractEfficiency
…/@totalBrakeEfficiency

Table 4 "Mean Efficiency Model" specific data used by ATM.

X-Path to data from Engine-File (/railml/rollingstock/vehicles/vehicle/engine/propulsion …)
…/tractiveVehicleEfficiency/valueTable
…/brakeVehicleEfficiency/valueTable

Table 5 "Efficiency Table Model" specific data used by ATM.

4.2.3.2 TypDef-File

The TypDef-File is an XML file and defines the types of energy storages, see also Figure 15. The Project-File will reference these types by an identifier. The TypDef-File observes the schema `schemas/TypeDefs.xsd` in plugin `de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm`. The HTML schema documentation is available in the GUI Help System at `OpenPowerNet User Guide > TypDef-File`.

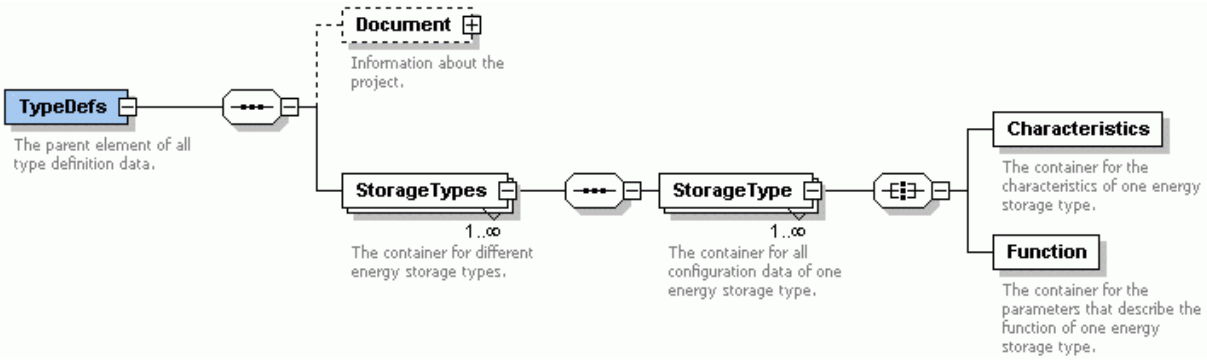

Document
Information about the project.
TypeDefs
The parent element of all type definition data.
StorageTypes
1..∞
The container for different energy storage types.
StorageType
1..∞
The container for all configuration data of one energy storage type.
Characteristics
The container for the characteristics of one energy storage type.
Function
The container for the parameters that describe the function of one energy storage type.

Figure 15 The elements of the TypDef-File schema.

4.2.3.3 Project-File

The project specific file is an XML file. It has to correspond with the OpenTrack infrastructure data. The corresponding schema file can be found in plugin `de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm` under `schemas/OpenPowerNet.xsd`. The HTML schema documentation with detailed information to each element and attribute is available in the GUI Help System at `OpenPowerNet User Guide > Project-File`. A sample XML file is available in plugin `de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm` under `projects/Sample_Network.xml`.

The Project-File has three main parts:

- ATM configuration,
- PSC configuration and
- Relations of courses to a Train Operating Company, see Figure 16.

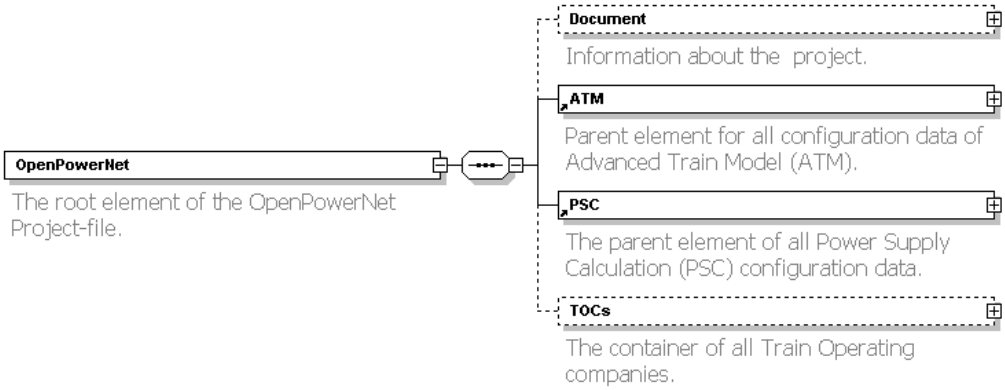

Document
Information about the project.
ATM
Parent element for all configuration data of Advanced Train Model (ATM).
OpenPowerNet
The root element of the OpenPowerNet Project-file.
PSC
The parent element of all Power Supply Calculation (PSC) configuration data.
TOCs
The container of all Train Operating companies.

Figure 16 The main branches of the Project-File in schema view.

Figure 17 to Figure 21 show an example Project-File.

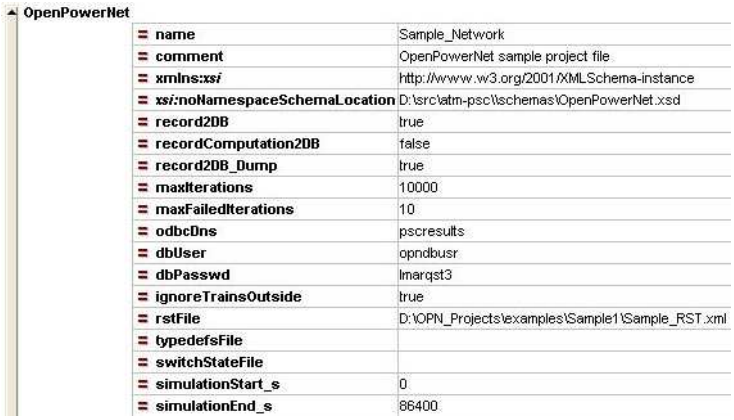


Figure 17 General configuration in OpenPowerNet Project-File.

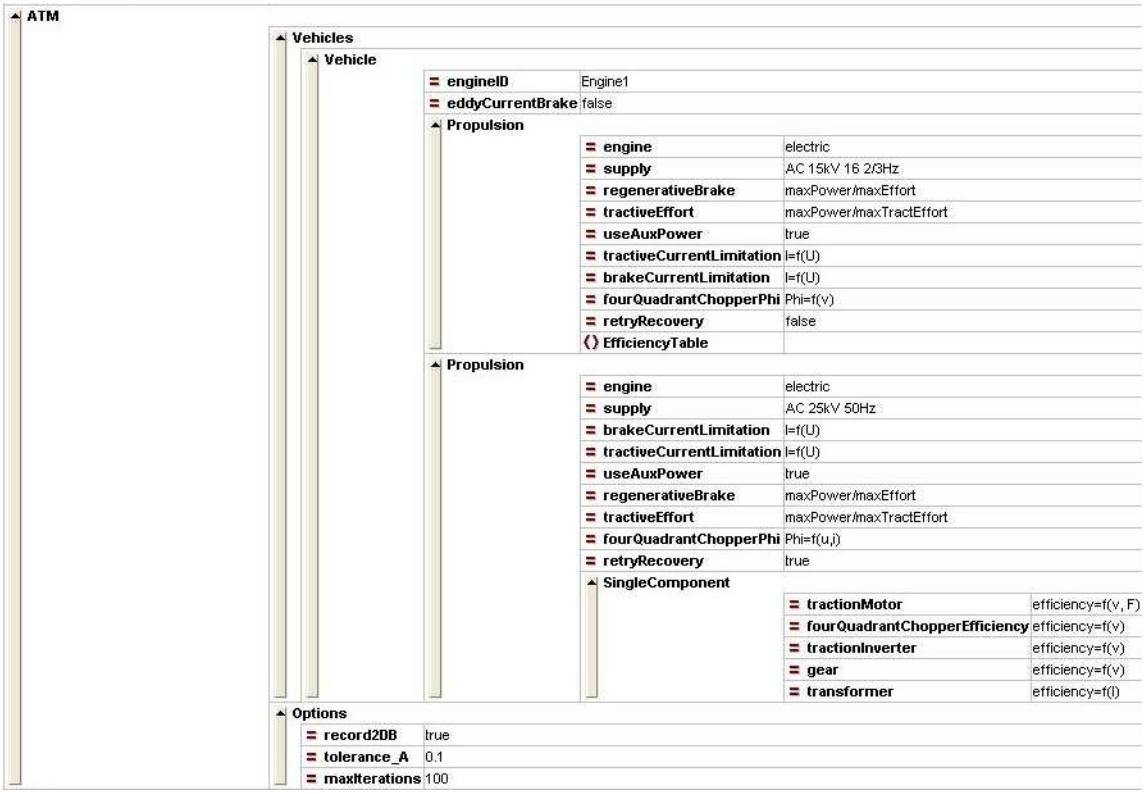


Figure 18 Example ATM configuration of one engine in the Project-File in Altova XMLSpy grid view.

This example uses a very detailed calculation with all propulsion components as efficiency curves for the AC 25kV 50Hz propulsion system, see Figure 18.

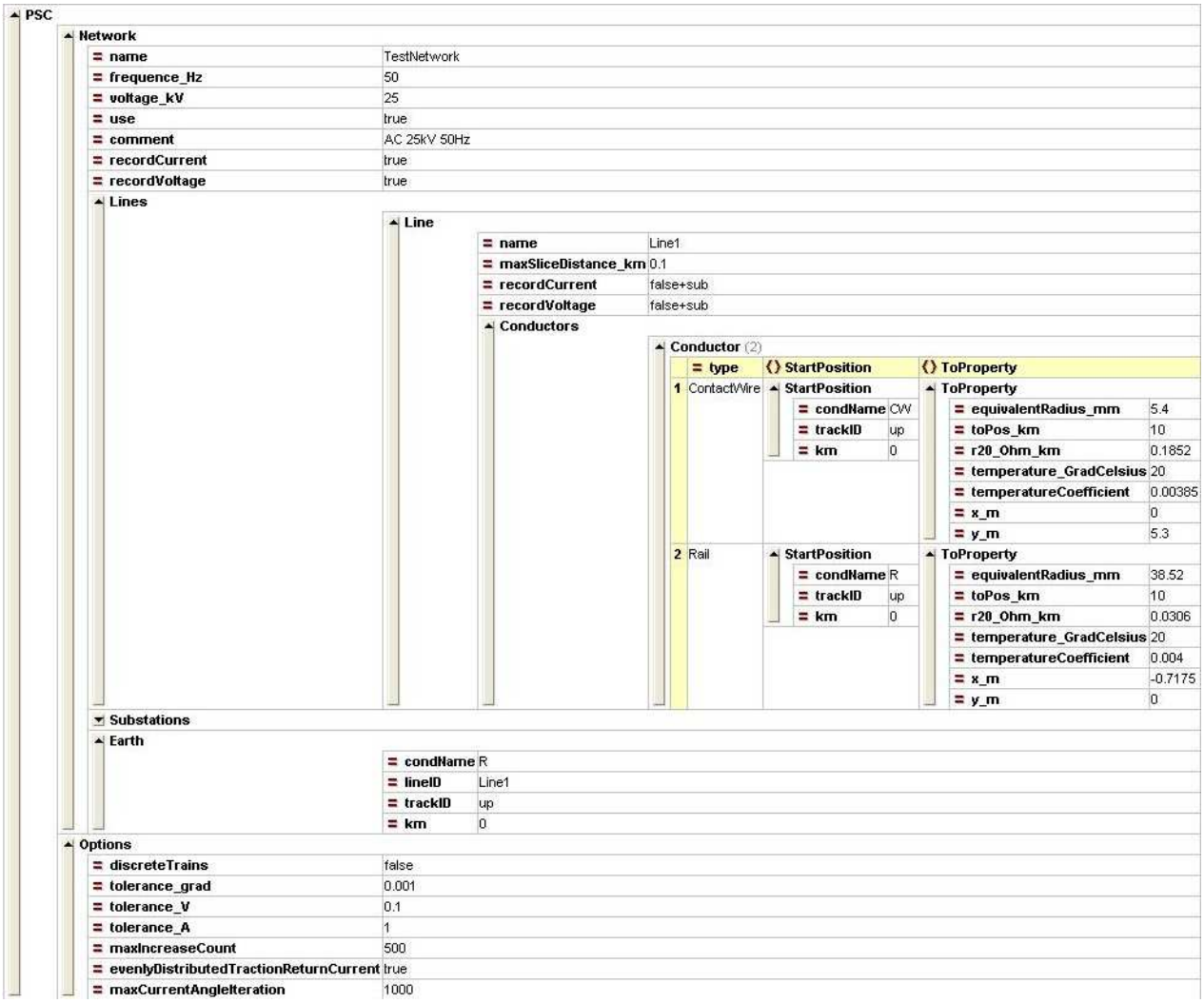


Figure 19 Example network configuration including line, substation, earthing node and general PSC options.

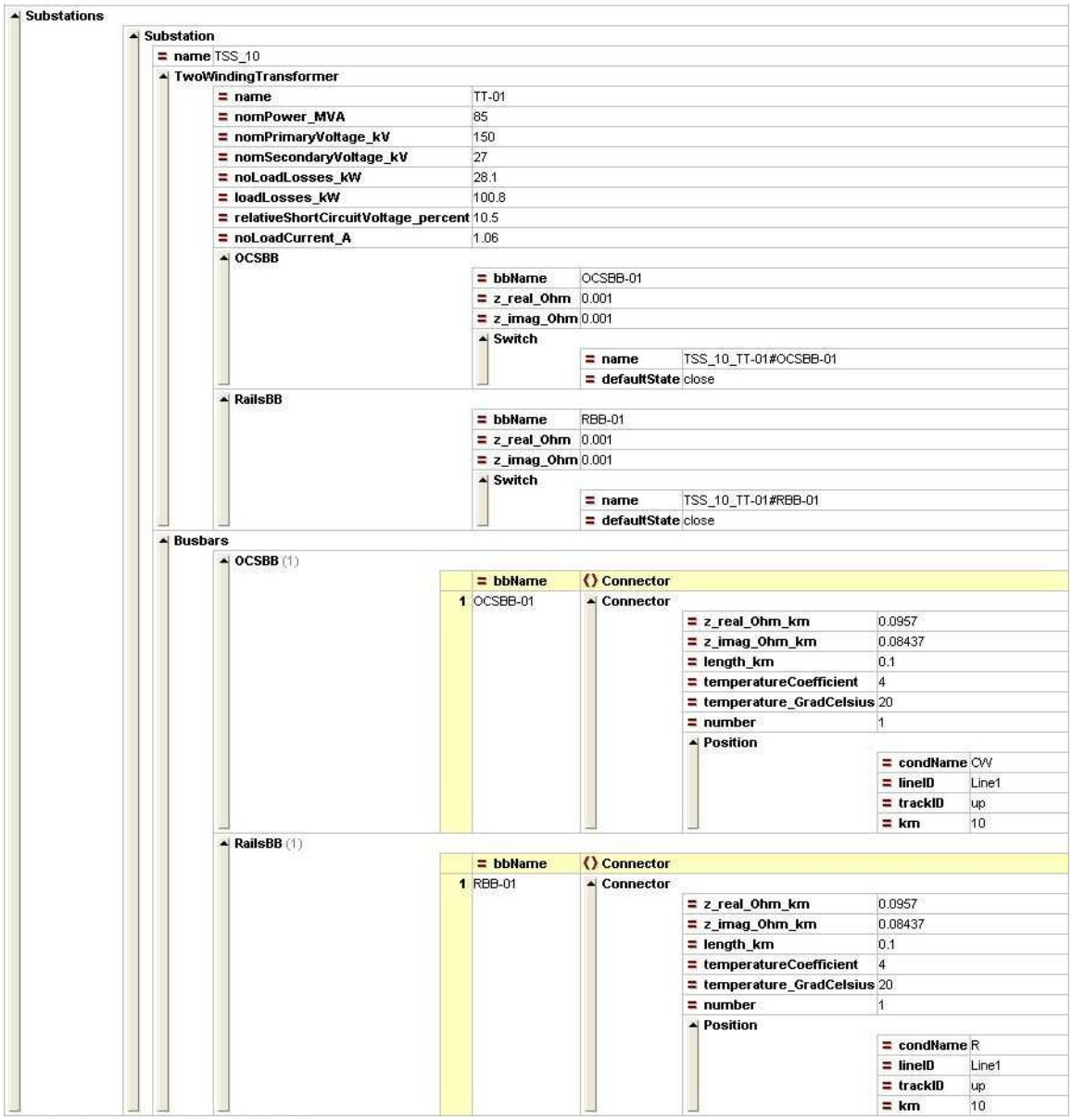


Figure 20 Substation element of example network configuration with transformer, busbars and feeder with switch.

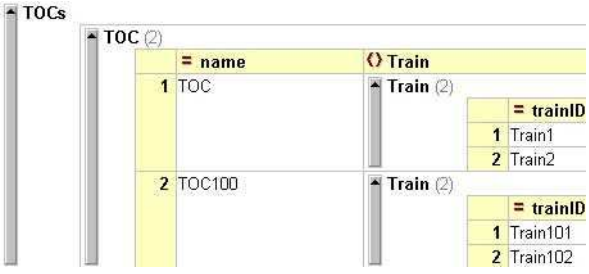


Figure 21 Example configuration of Train Operating Companies.

For accumulation of energy consumption several courses can be grouped to so-called Train Operating Companies. This feature can be used to attribute a portion of energy to different operators, type of trains or any arbitrary selection by using the courses specified in the

Project-File, see Figure 21. The attribute `trainID` corresponds with the course ID in OpenTrack. The consumed energy of not specified courses is summarised for a Train Operating Company with the name `unknown`. Therefore it is not advised to name a Train Operating Company `unknown`!

Besides the configuration of the engine model, network and operating company it is necessary to define recording of simulation results. To record data to the database the connection properties need to be set. The configuration of recording is structured hierarchical. The attributes in element `OpenPowerNet` are at the highest level and define the general recording behaviour, see XML snippet below.

```
<OpenPowerNet
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="http://www.dd.bahntechnik.de/opn/schemas/1.1.0/b6/OpenPowerNet.
xsd"
name="Tutorial AC Network"
comment="failure scenario"
maxIterations="1000"
maxFailedIterations="100"
dbUser="opndbusr" (The database user name)
dbPasswd="lmarqst3" (The database user password)
odbcDsn="pscresults" (The DSN name, this is the name specified as ODBC data source name.)
record2DB="true" (Whether to record data to database or not, default is false.)
record2DB_Dump="false" (Whether to use dump files to speed up the simulation, default is
false.)
recordComputation2DB="false" (Whether to record computation data during ATM ⇔ PSC iteration,
it is not recommended to set this value to true, default is false. The data recorded with this
option is not necessary for analysis.
rstFile="D:\OPN_Projects\Tutorial\01_AC_Network\OPNData\Engine-File.xml"
switchStateFile="D:\OPN_Projects\Tutorial\01_AC_Network\OPNData\Switch-File.xml">
```

To record engine data set the attribute `/OpenPowerNet/ATM/Options/@record2DB` to `true`.

The recording of currents and voltages for electrical networks is configured according to the element hierarchy of the Project-File beginning at element `/OpenPowerNet/PSC/Network` using the attributes `recordCurrent` and `recordVoltage`. These two attributes have three allowed values:

- `true`: Record data of this element if higher hierarchy is not set to `false+sub`.
- `true+sub`: Record data of this and all lower elements.
- `false+sub`: Do not record data of this and all lower elements.

To record the data of a storage set the attribute `recordStatus` in element `/OpenPowerNet/PSC/Network/Substations/Substation/Storage` to `true`. This attribute is directly inherited from the top level attribute of the hierarchy.

Example XML snippet with recording attributes:

```
<Network
name="A"
frequency_Hz="0"
voltage_kV="0.6"
recordCurrent="true" Record currents for this network.
recordVoltage="true"> Record voltages for this network.
  <Lines> No recording attributes set therefore the default value (true) will be applied.
    <Line
name="A"
recordCurrent="false+sub" Do not record currents for this line and all subordinate elements.
recordVoltage="false+sub"> Do not record voltages for this line and all subordinate elements.
...
    </Line>
  </Lines>
  <Substations
recordCurrent="true" Record currents for all substations if not contrary defined for a
specific substation.
```

```
recordVoltage="true"> Record voltages for all substations if not contrary defined for a
specific substation.
    <Substation
name="TSS_A"
recordCurrent="true" Record currents for this substation.
recordVoltage="true"> Record voltages for this substation.
...
    </Substation>
    <Substation
name="BC"
recordCurrent="false+sub" Do not record currents for this substation.
recordVoltage="false+sub"> Do not record voltages for this substation.
      <Busbars>
...
      </Busbars>
      <Storage
name="1"
storageReference="Typ_600V"
recordStatus="true"> Record status for this storage including storage currents and voltages.
        <BusbarFrom bbName="ocsbb"/>
        <BusbarTo bbName="railsbb"/>
      </Storage>
    </Substation>
  </Substations>
  <Earth lineID="A" trackID="up" km="0" condName="E"/>
</Network>
```

Please note that recording line voltages and currents increases the amount of written data significantly and slows down the simulation as well as the analysis. Record these values only if necessary!

The tables below list some typical configuration data for power supply.

Two Winding Transformer	
nomPower_MVA	10
nomPrimaryVoltage_kV	115
nomSecondaryVoltage_kV	16.25
noLoadLosses_kW	6.5
loadLosses_kW	230
relativeShortCircuitVoltage_percent	10.7
noLoadCurrent_A	0.06

Table 6 Typical two winding transformer configuration.

Three Winding Transformer	
nomPower_MVA	85
nomPrimaryVoltage_kV	150
nomSecondaryVoltage_kV	53.8
noLoadLosses_kW	38
loadLosses_kW	136
relativeShortCircuitVoltage_percent	8.6
noLoadCurrent_A	1.43

Table 7 Typical three winding transformer configuration.

Auto Transformer	
nomPower_MVA	20
nomPrimaryVoltage_kV	55
nomSecondaryVoltage_kV	27.5

Auto Transformer	
noLoadLosses_kW	8
loadLosses_kW	17
relativeShortCircuitVoltage_percent	1.76
noLoadCurrent_A	0.33

Table 8 Typical auto transformer configuration.

Rectifier	
internalResistance_Ohm	0.015
nomVoltage_kV	0.750
energyRecovery	false

Table 9 Typical rectifier configuration.

Storage		
Characteristics	type	simple
	maxLoad_MWs	15
	initialLoad_MWs	15
	lossPower_kW	0.1
	loadRi_Ohm	0.005
	unloadRi_Ohm	0.005
	auxPower1_kW	10
Function	minLoadAllowUnload_MWs	0
	loadMaxCurrent1_A	200
	unloadMaxCurrent1_A	1400
	voltage1LoadStart_kV	0.725
	voltage1LoadStop_kV	0.720
	voltage1UnloadStart_kV	0.715
	voltage1UnloadStop_kV	0.720

Table 10 Typical storage configuration.

Type	**Name**	**Description**	**R_{20} [Ohm/km]**	**equivalent radius [m]**	**temperature coefficient**
contact wire	Ri150	150mm²	0,1185	0,0054	0,00393
	Ri120	120mm²	0,1481	0,0048	0,00393
messenger wire	Cu150	150mm²	0,1185	0,00531	0,004
	Cu120	120mm²	0,1481	0,00468	0,004
feeder	Al 625	625mm²	0,0459	0,01092	0,004
	Al/St260/23	260mm² Al & 23mm² steel	0,1068	0,00733	0,004
rail	UIC60		0,0306	0,03852	0,004
	UIC54		0,0339	0,03659	0,004
third rail	Al 5100	Al 5100mm²	0,0064	0,0314	0,00382
	Fe 7600	7600mm² steel	0,0159	0,0383	0,005

Table 11 Typical conductor configuration values.

4.2.3.4 Switch-File

The optional switch state file is an XML file. It observes the schema `schemas/ADE.xsd` in plugin `de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm`. The HTML schema documentation can be found in the GUI Help System at `OpenPowerNet User Guide > Switch-File`.

The Switch-File configures the state changes for each switch in the power supply network during the simulation time. The default state of the switch is configured in the Project-File. The Switch-File is only needed if switch states shall be changed during the simulation.

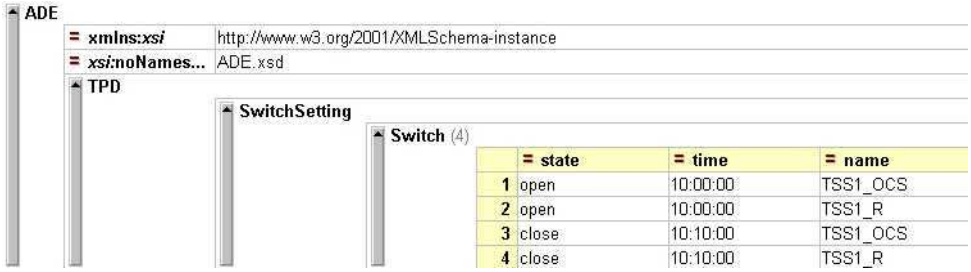


Figure 22 Switch configuration for network calculation. The switches are open for 10 minutes beginning at 01:00:00. This means the substation is disconnected from the line, see Figure 20.

4.3 Simulation

The OpenPowerNet GUI handles the start and stop of the three modules APserver, PSC and ATM. To start the modules, `Start OpenPowerNet` has to be selected from the context menu of the particular Project-File.

The OpenPowerNet settings in OpenTrack have to be configured to run co-simulations, see Figure 14. The simulation can be started as usual with OpenTrack simulation panel.

Further details on how to start and stop OpenPowerNet and how to run the simulation are available in the GUI Help System, see `OpenPowerNet User Interface User Guide > Usage`.

4.4 Visualisation

All simulation results are stored in a database. For visualisation the data can be transferred into a custom Excel table sheet via external data exchange, see and follow the instructions below from Figure 23 to Figure 31.

Figure 23 Create a new external data query.

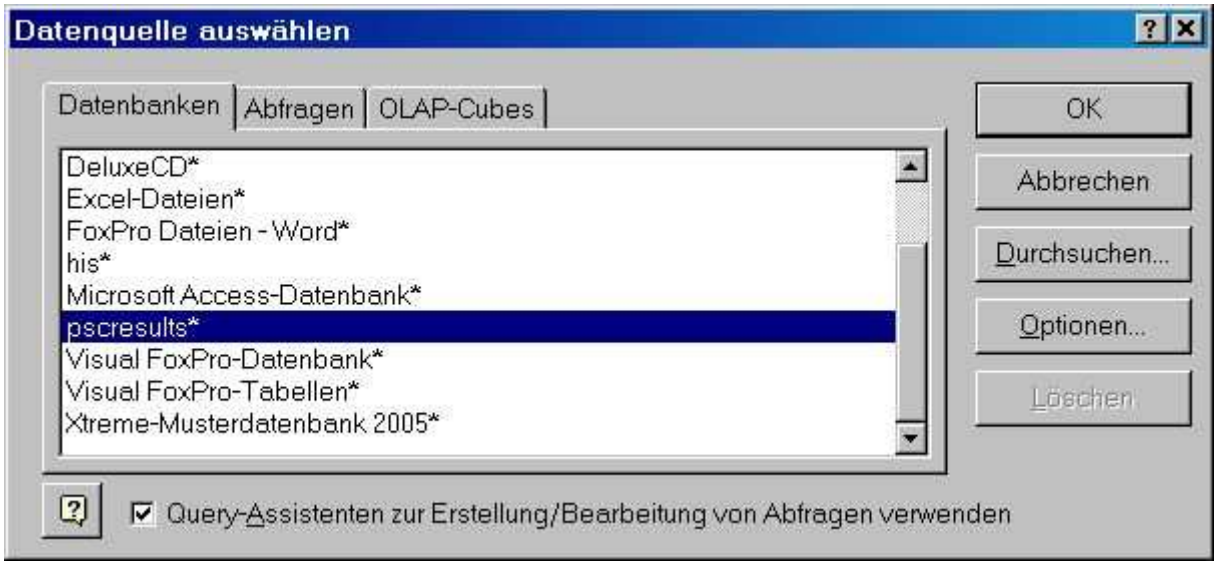


Figure 24 Select `pscresults*` as external data source.

Make sure the DSN selected in Figure 24 uses the `MySQL ODBC 3.5.1 Driver`. The steps below will not work with the `MySQL ODBC 5.1.x Driver`! If no such DSN is available see document Installation Instruction to create a new DSN. You can find the Installation Instruction in the Help System `OpenPowerNet User Guide > Documents`.

Figure 25 For this example select table `sim`, add the columns shown on the right to the query and click next.

Figure 26 Click next, do not filter any data.

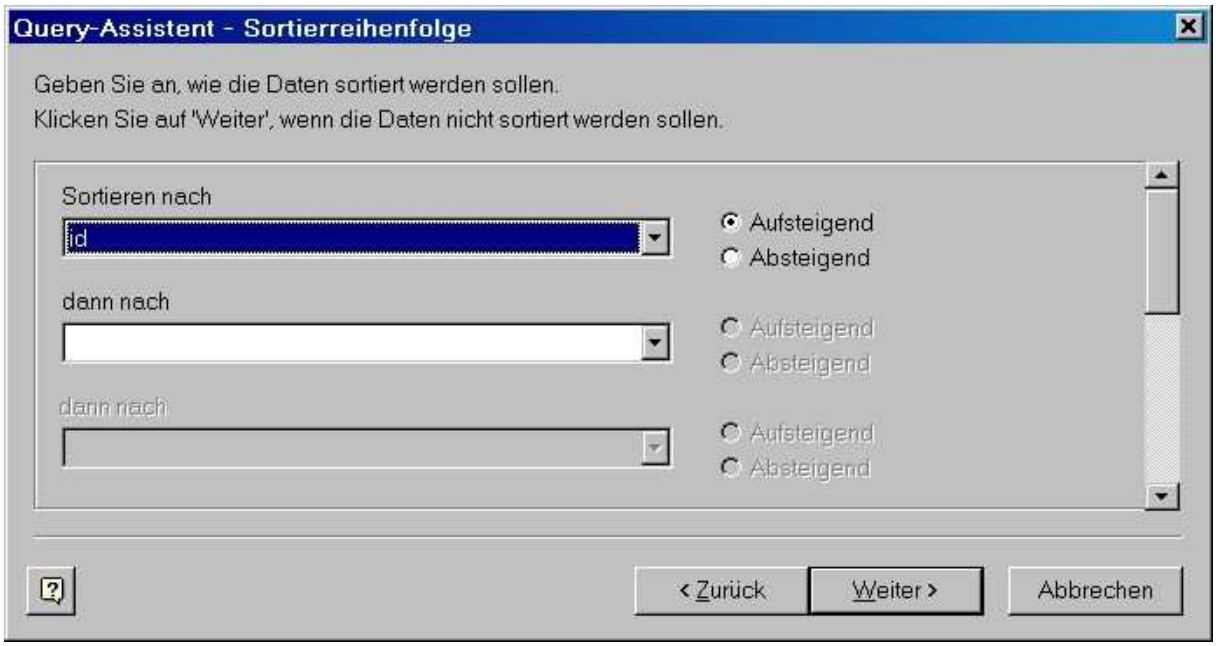


Figure 27 Select `id` in the upper combo box to sort by the column `id` of table `sim`.

Figure 28 Select the centre radio button and click finish.

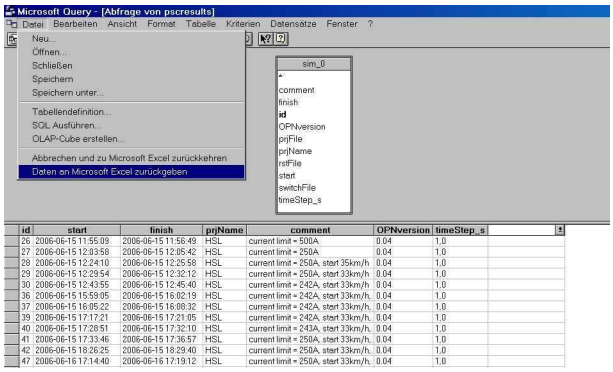


Figure 29 The results of the query are listed in the table. Select `Return Data to Microsoft Excel` from file menu to insert the data into an Excel table. Please see the Excel documentation for further questions.

Figure 30 Click OK and the data will be inserted to the table at position A1.

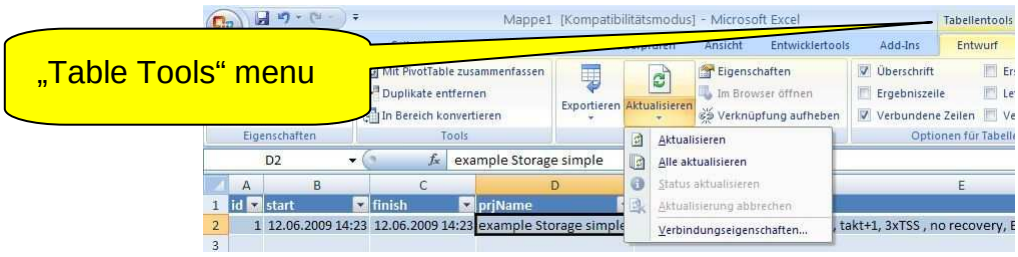


Figure 31 Now the data in the table retrieved from database is ready for further evaluation and visualisation. For easy handling of the external data source query it is recommended to use the “Table Tools” menu.

OpenPowerNet comes with Excel files already prepared for data analysis. These files are accessible from the GUI. See the GUI Help System at `OpenPowerNet Analysis User Guide > Usage` for details.

The Excel-File `Consumption.xls` visualises the energy consumption of all courses in all networks of the simulation summarised by the Train Operating Company, see Figure 21, and expressed as percentage of total energy consumption of all courses, see Figure 32.

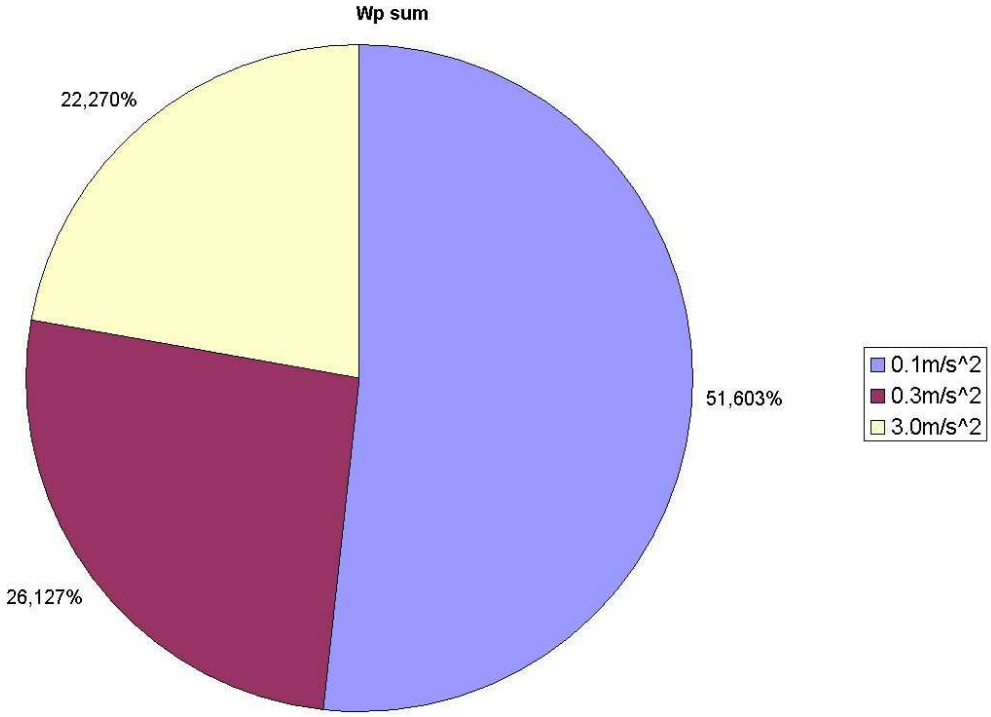


Figure 32 Proportional portioned energy consumption of Train Operating Companies expressed in percent of the total energy consumptions of all Train Operating Companies.

4.5 Analysis

The Analysis Tool is available from the GUI OpenPowerNet menu and starts up as a separate application, see Figure 33. Messages from the tool are displayed in the GUI console with name “OPN”. These messages give information about the progress of the analysis, warnings and failures.

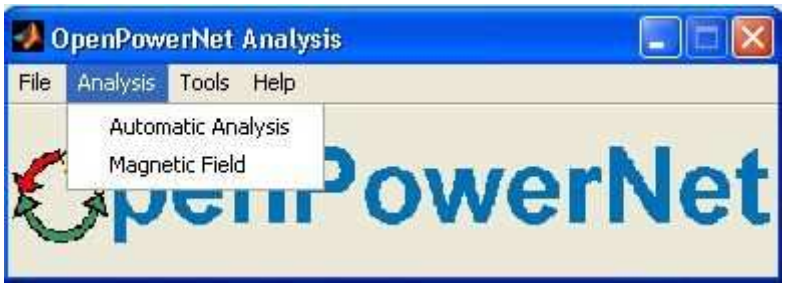


Figure 33 The Analysis Tool main window.

4.5.1 File > Setup

The setup define the output directory (Figure 34) and the default ODBC connection (Figure 35). Restart the application to make your changes effective.

Figure 34 The dialog to select the default output directory.

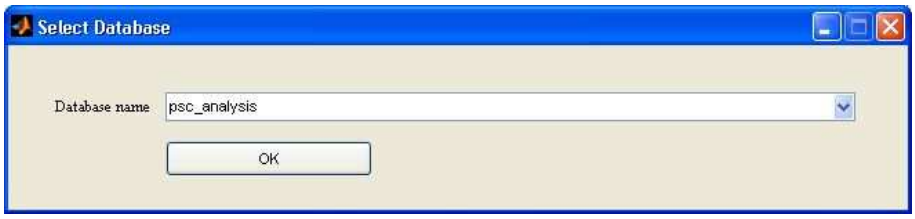


Figure 35 The dialog to choose the default connection from the list of available ODBC connections.

4.5.2 Automatic Analysis

The automatic analysis window provides the selection of the simulation to analyse. Once a simulation is selected the selection has to be locked with the provided button. Next is to choose the time window for the analysis. The selected time window includes the start but not the end time. Then change the designation or use the one provided by default. The designation is used in the diagram titles of the generated Excel files.

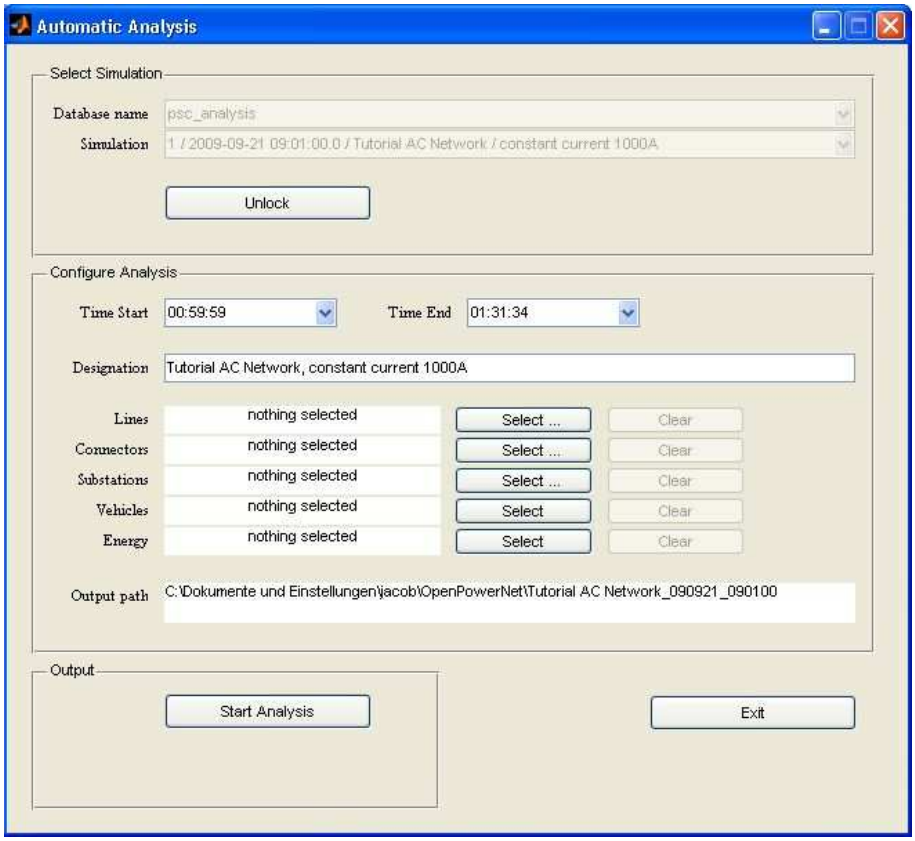


Figure 36 The automatic analysis window to select the simulation, configure and start the analysis.

Next is to select the diagrams to be generated. These diagrams are divided into different groups according to the select options available in Figure 36.

For `Lines`, `Conductors` and `Substations` a new dialog open. See the following chapters for a detailed description.

`Vehicles` and `Energy` can only be selected or not and no extra dialog open.

The output path displays the actual setup.

After all configurations are finished the button `Start Analysis` will start the analysis. In the console with name “OPN” of the GUI all messages from the analysis process are displayed. At the beginning of each analysis the message console will be erased.

Note: Before the analysis start close Excel and during the analysis do not use Excel!

4.5.2.1 Lines

The Lines group provides diagrams along the line. These diagrams are:

- U_Panto f = (s): The pantograph voltage of the courses along the line. If selected also conductors of type ContactWire with reference to conductors of type Rail.
- U_Rail-Earth f = (s): The potential between conductors of type Rail to the conductor of type Earth.

- U_Conductors f = (s): The potential between any conductors to a reference. As reference any conductor is allowed but should be whether only one per line or one per all tracks!
- I_Leakage f = (s): The current between any conductors to a reference in amps per meter. As reference any conductor is allowed but should be whether only one per line or one per all tracks!

The selection dialog provides the following columns:

- Name:
  To specify the name of the diagram. If set the default diagram title will be replaced with the given text. The designation will be added to the title and the subtitle with name of line and tracks will still be used.
- Type:
  The type of the diagram.
- Line xyz:
  The name of a line grouping different tracks.
- Track xyz:
  The name of a track grouping different conductors.
- Panto:
  The column to select the curves for pantograph voltage belonging to the track and line indicated in the rows above.
- Conductor Name xyz:
  The column to select the curves for the conductor with name xyz belonging to the track and line indicated in the rows above.

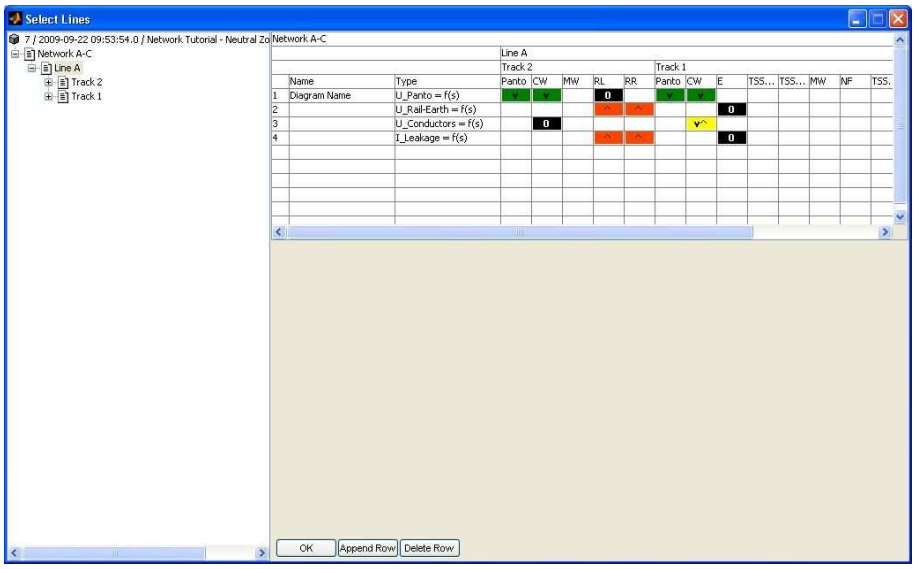


Figure 37 The dialog to configure the diagrams versus the line position.

The columns displayed at the right side depend on the selection in the tree of the left side. In Figure 37 all conductors for line A are displayed.

The table provides the following selection options:

- ^: Only the maximum values out off all time steps.
- v: Only the minimum values out off all time steps.
- v^: The minimum and maximum values out of all time steps.
- 0: The reference.

The buttons `Append Row` and `Delete Row` add a new respective delete the selected row.

The select lines dialog close when pressing the `OK` button.

4.5.2.2 Connectors

The Connectors group provides diagrams for connectors specified in the Project-File under XML element `/OpenPowerNet/PSC/Network/Connectors`.

These diagrams are:

- U,I = f(t):
  The curves of the voltage between the both ends of the connector and the current thru the connector versus the time.
- U, I, Isum = f(t):
  Same as above plus the current sum of all selected connectors.
- P = f(t):
  The power consumed by the connector versus time.
- P, Psum = f(t):
  Same as above plus the sum of all selected connectors.
- I = TRLPC:
  The current of the selected connector as the **T**ime-**R**ated **L**oad **P**eriods **C**urve.
- P = TRLPC:
  The power of the selected connector as the **T**ime-**R**ated **L**oad **P**eriods **C**urve.

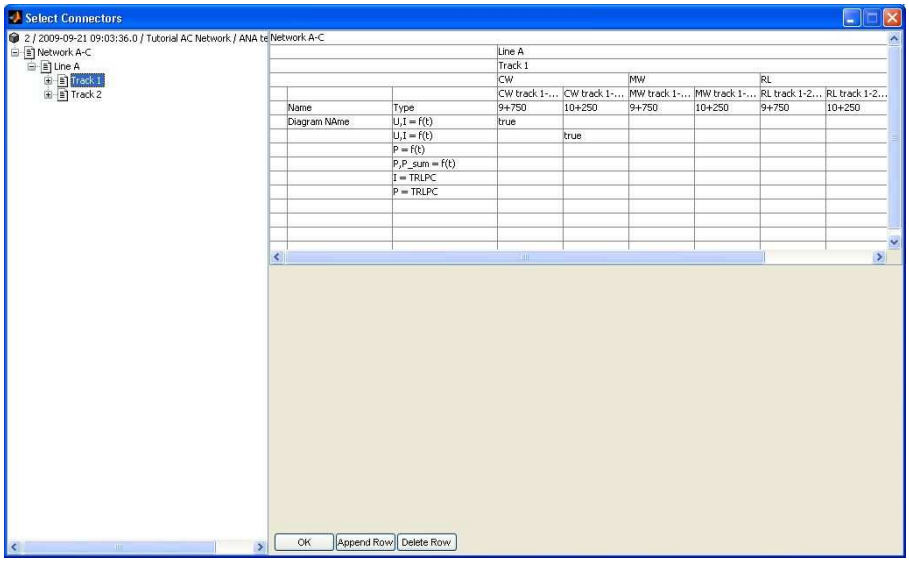


Figure 38 The dialog to select connectors and to configure different diagrams.

The columns displayed at the right side depend on the selection in the tree of the left side.

4.5.2.3 Substations

The Substations group provides diagrams related to substations. A dialog opens when pressing `Select ...`, see Figure 39.

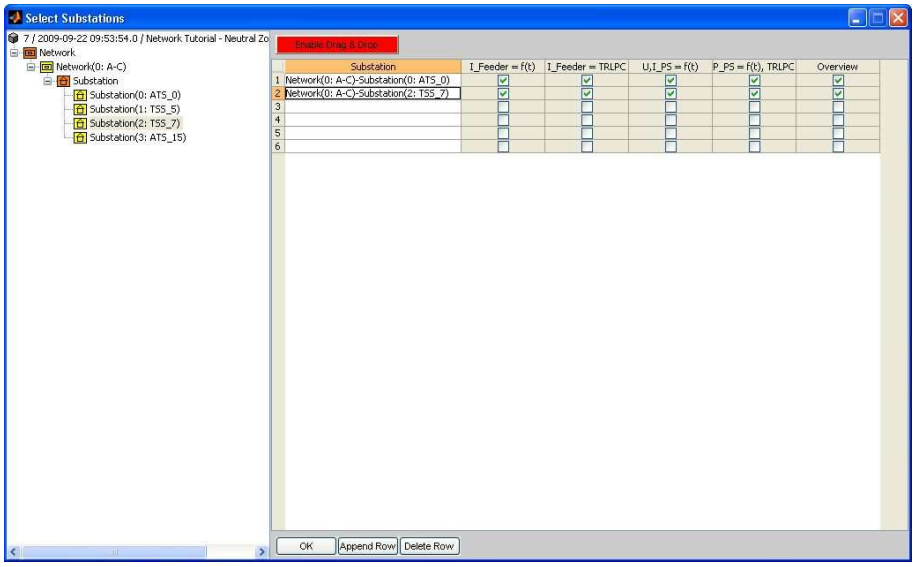


Figure 39 The dialog to select the substations and the diagrams to be generated.

On the left side all substations are available as a tree view. On the right side is the table with selected substations and the diagram types. To add substation to the table click first the red button `Enable Drag & Drop`, then select a substation and then click in a row of the table. By default all diagram types are selected.

The following diagram types are available:

- I_Feeder = f(t):
  The feeder cable current versus time.
- I_Feeder = TRLPC:
  The feeder cable current as time-rated load period curves
- U,I_PS = f(s):
  The voltage and current versus time for each power supply within the substation.
- P_PS = f(s), TRLPC:
  The power versus time and as time-rated load periods curve for each power supply within the substation.
- Overview:
  Overview of values for feeders and power supply like RMS of current and power.

At the end click OK to return to the Automatic Analysis window.

4.5.3 Magnetic Field

The Magnetic Field Tool calculates the magnetic field at a specific location for a specific time as a diagram or as a movie over a time period.

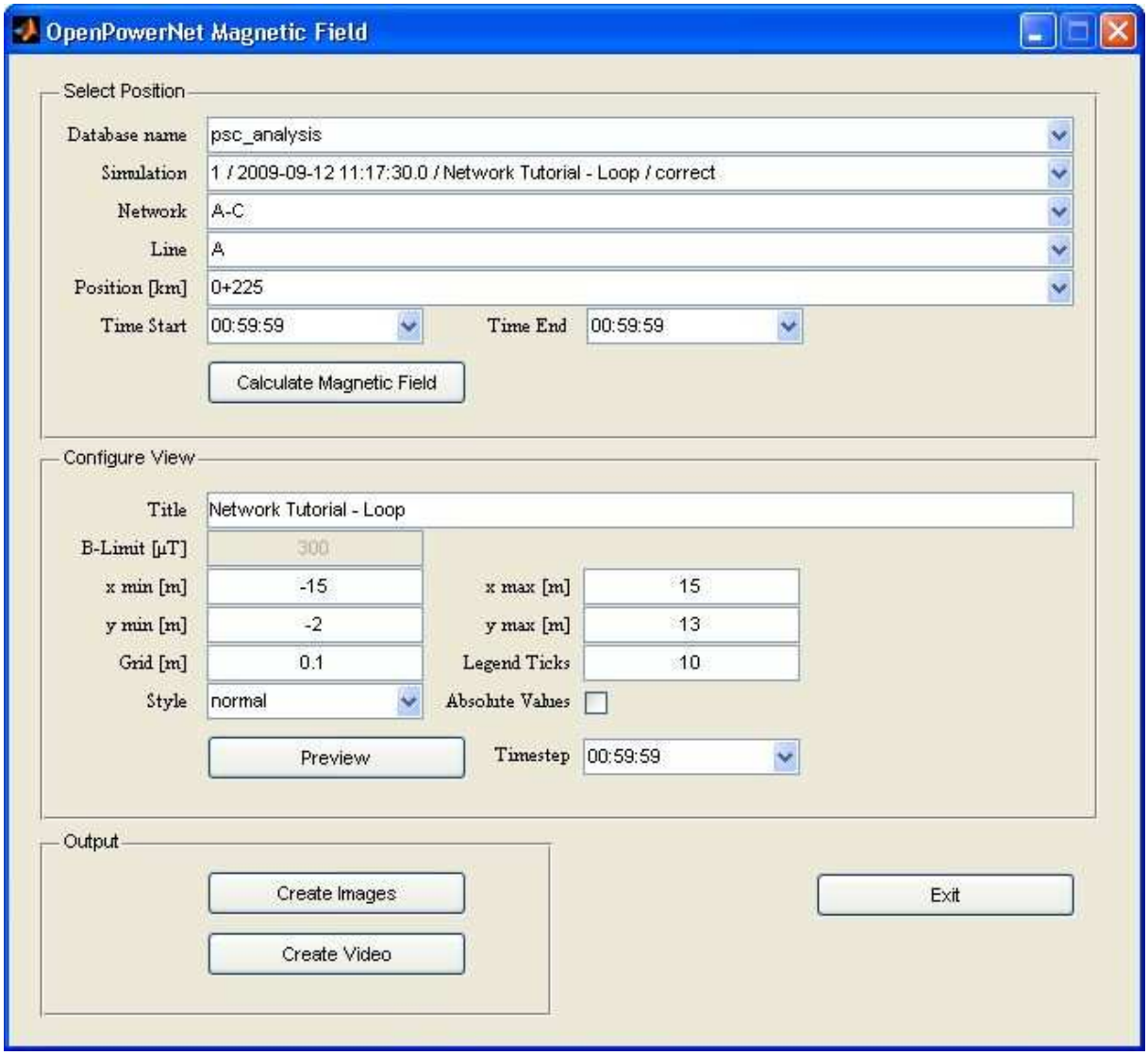


Figure 40 The Magnetic Field Tool window.

First the position and time period of the magnetic field need to be defined. Then the calculation of the values starts with click on button `Calculate Magnetic Field`.

Then the diagram configuration is enabled. The diagram style is normal or as ISO-lines and the values may be absolute or not. A preview at a specific time step is possible.

The output is available as separate pictures or as movie made from the single pictures.

4.5.4 Tools

The Analysis Tool provides an editor to change the comment of the simulation in the database. This comment is used e.g. as part of the default designation for diagram titles.

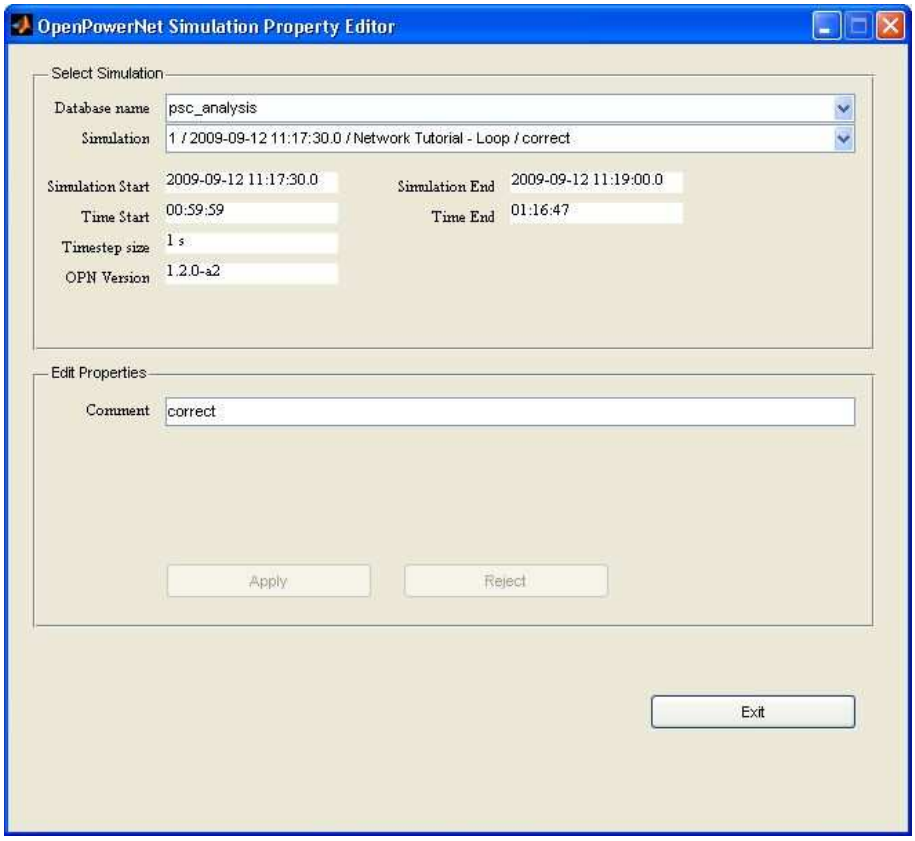


Figure 41 The simulation property editor of the analysis tolll.

4.6 Database tasks

All simulation results are stored in a database. This database needs to be maintained by the user. The following tasks are available via the GUI:

- Create new database schema,
- Export data from database,
- Import data into database and
- Upload dump files into database.

The detailed description of all tasks is available in the Help System under `OpenPowerNet User Interface User Guide > Usage`.

5 Required technical data for the simulation

Track alignment and signalling

- Track layout,
- Chainage,
- Longitudinal declination (begin, end, gradient, sign),
- Begin and end of single or multiple track sections,

- Position of switches, crossings and junctions,
- Begin, end and radius of bending / curves,
- Begin and end of tunnels,
- Begin and end of different track types and rail profiles,
- Position and kind of signals and signalling sections,

Operational data

- Position of passenger stations and signal-related stopping points,
- Permissible speed profiles,
- Stopping times at stations, turning times at termini,
- Time-table of all line sections (including internal rides),
- Train types, train configuration and loading grade per section,
- Operation concept, incl. special operational scenarios,

Vehicle data

- Vehicle or train mass (empty, laden),
- Adhesion mass,
- Maximum speed,
- Driving resistance formula,
- Factor for rotating mass,
- Propulsion characteristics as follows:
  - Traction force and braking force characteristics related to running speed;
  - Pantograph current characteristics (driving and braking) related to running speed or efficiency characteristic;
  - Information about voltage-related current or power limitation of the propulsion control,
  - Maximum / average power consumption of the auxiliary systems (lighting, air condition, heating),
  - Maximum recuperation voltage.

Power supply system and conductor data

- Type of substation,
- Nominal voltage,
- Position of substations (connection points to the power grid),
- Feeding scheme (sectioning inclusive chainage),

- Busbar voltage of the substations (line-side, no-load and nominal load)
  - if available: internal resistance of the substations respectively short-circuit voltage of the converter transformers,
- If available: settings of the transformer and converter protection devices (e.g. I>/t, I>>),
- If available: protection settings of the power rail overload protection devices (I>/t, I>>, di/dt etc.),
- Number, length and cross section of feeding and return current cables (from substation to track or connections from track to track),
- Position of feeding points and return current cable connection points to the power rails,
- Type of catenary (number and cross section of single conductors),
- Additional feeding conductors (connection points and cross section),
- Switch state of the power rail system,
- Position and cross section of rail and track bonds.

6 Tutorial

This tutorial is a step by step description how to use OpenPowerNet. It starts with the folder structure, continues with the configuration then simulation and analysis for four different types of networks.

If you do not want to create the configuration files you can go to `OpenPowerNet User Guide > PDF-Documents` download them and the database backup from the Help System as zip-files. Please read chapter 4.6 for the description of the database import.

6.1 General

It is advised to always use the same folder structure for all simulations as it helps to keep order. In principle each simulation has two kinds of data. One kind is the input & analysis data and the other kind the output data.

Input and analysis data structure:

```
.../Project_Name
   +- OPNAnalysis (output directory for the Analysis Tool)
      * ...
   +- OPNData (OpenPowerNet configuration data)
      * Engine-File.xml
      * TypDef-File.xml
      * Project-File.xml
   +- OTData (OpenTrack configuration data)
      * Project_Name.depot
      * Project_Name.courses
      * Project_Name.dest
      * Project_Name.stations
      * Project_Name.timetable
      * Project_Name.trains
   +- OTDocuments (OpenTrack infrastructure)
      * Project_Name.opentrack
   +- OTOutput (OpenTrack output directory)
      * ...
```

The folder and file structure above has to be prepared manually.

For the output data structure refer to chapter 3.7.

To achieve a correct simulation result it is necessary to have sufficient information about the railway, electrical network and engines. For a detailed list of required technical information please see chapter 5. The following list is a minimum of necessary information to create the configuration data.

OpenTrack:

- Track layout (length, curves, gradients, points, crossings)
- Timetable
- Engine (effort-speed-diagram, weight, resistance formula values, auxiliary power)
- Signalling system

OpenPowerNet:

- Electrical network (layout, conductor and connector characteristic)
- Power supply (transformer or rectifier data, feeder cable characteristic)
- Switch (position and default state)
- Engine (effort-speed-diagram or maximum power & maximum effort, efficiency, auxiliary power)

As editor for the XML-Files we use Altova XMLSpy. Any other text editor can be used as well but for convenience it should be an XML-Editor that can use an XML-Schema to evaluate the XML-File and gives editing support. While editing the file it is advised to open the Info-Window to see the description to the selected element or attribute as well as to open the Editing-Support-Window, see Figure 42.

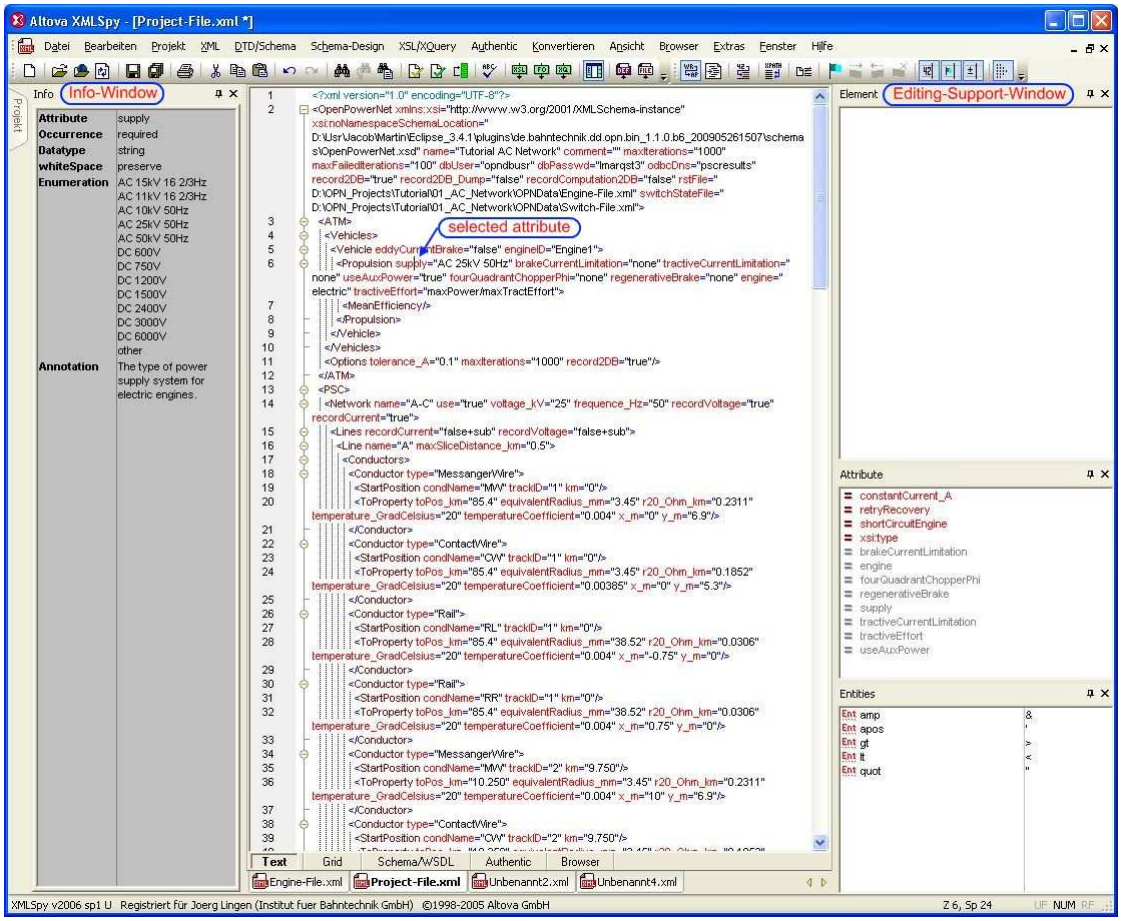


Figure 42 The Altova XMLSpy with a Project-File and opened Info-Window and Editing-Support-Window showing the context according to the selected attribute.

6.2 AC Network tutorial

In this tutorial we will create a single line to learn how to set up a simple OpenTrack and OpenPowerNet co-simulation. The line shall have three stations and a 25kV 50Hz AC power supply system with two substations. We will have two kinds of trains and a very simple timetable with four courses. Never the less we will have an interesting simulation with OpenPowerNet and we will compare the normal operation with a failure scenario.

6.2.1 Configuration

6.2.1.1 OpenTrack

The first step in OpenTrack is to create a new set of preferences. To do so save first the set with a new name and then set the path and file names, see Figure 43 for details.

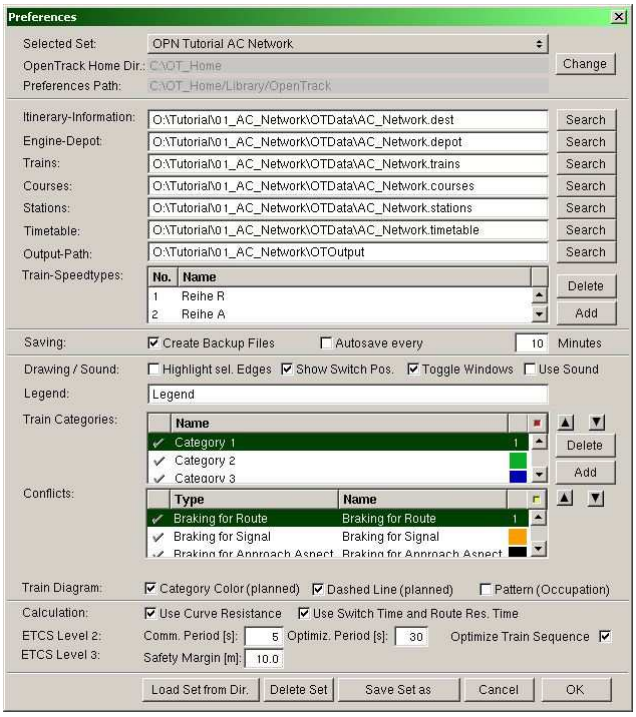


Figure 43 OpenTrack preferences

The next step is to create the track layout, signals, stations and power supply area.

The detailed track data is:

- Start at km 0 with home signal
- Station A at km 0+200
- Exit signal at km 0+400
- Gradient of 10‰ from km 1+400 to 2+400
- Gradient of 0‰ from km 2+400 to 6+750
- Gradient of -5‰ from km 6+750 to km 8+750
- Gradient of 0‰ from km 8+750 to the end of the line

- Home signal at km 9+650
- Turnout at km 9+750
- Exit signals on both tracks at km 9+800
- Station B at km 10+000 with two tracks
- Exit signals on both tracks at km 10+200
- Turnout at km 10+250
- Home signal at km 10+350, set sight distance to 10000m to prevent braking of courses while approaching the signal
- Exit signal at km 85+000
- Station C at km 85+200
- End of line and exit signal at km 85+400
- Line speed is 75km/h from km 0+000 to 10+350 and 200km/h until km 84+400
- Power supply area of AC 25kV 50 Hz

The line name is “A” and the track name is “1”. Only the siding in Station B has the track name “2” but the same line name.

Group the station areas and create all routes, paths and itineraries. The courses shall run from Station A via track “2” in Station B to Station C and from Station C via track “1” in Station B to Station A.

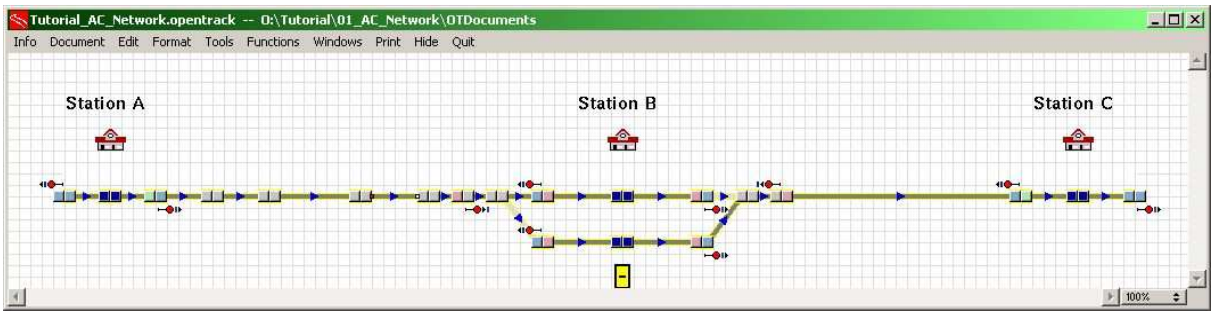


Figure 44 The OpenTrack infrastructure including tracks, signals, stations and power supply area.

After the infrastructure is built we need to define an engine and trains before we can configure the courses and a timetable.

Engine data:

- Name is “Engine1”
- Max effort is 250kN
- Max power is 5.56MW, => constant power is in the speed range from 80km/h with 250kN to 250km/h with 80kN
- Propulsion system is AC 25kV 50Hz
- For further details see Figure 45

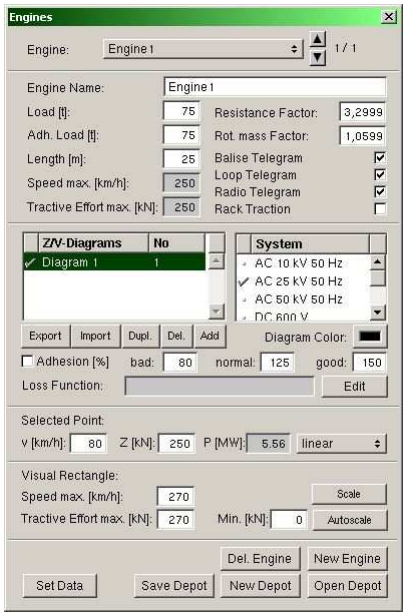


Figure 45 The properties of engine "Engine1" in OpenTrack.

Now we can define trains. We will use two types of trains, a short and a long train. The short train only has one trailer and the long train has 14 trailers with 20t load, 25 m length and 30kW auxiliary power, see Figure 46.

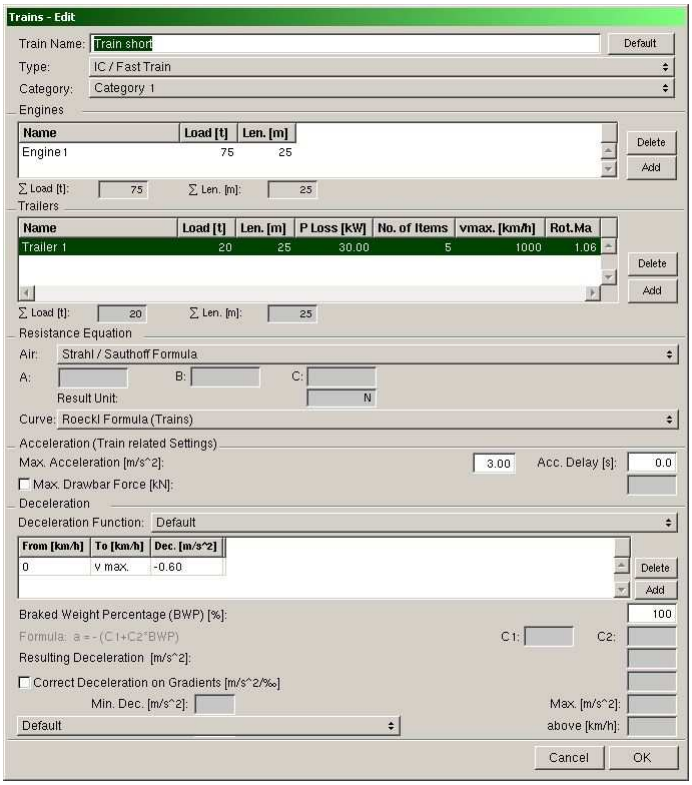


Figure 46 The configuration data of train "Train short" in OpenTrack with one engine and one trailer.

As we now have trains we are able to define courses and their timetable. We will use four courses, two from Station A to Station C and two from Station C to Station A.

Course and timetable details:

- course “ABCl_01” from Station A to Station C via track 2 in Station B with 60s wait time, departure is 01:00:00, Train long
- course “ABCs_02” from Station A to Station C via track 2 in Station B with 60s wait time, departure is 02:00:00, Train short
- course “CBAl_01” from Station C to Station A via track 1 in Station B with 60s wait time, departure is 01:00:00, Train long
- course “CBAs_02” from Station C to Station A via track 1 in Station B with 60s wait time, departure is 02:00:00, Train short

To get the departure and arrival times run the simulation and adjust the planned to the actual data. After you have done so the train diagram should look like Figure 47.

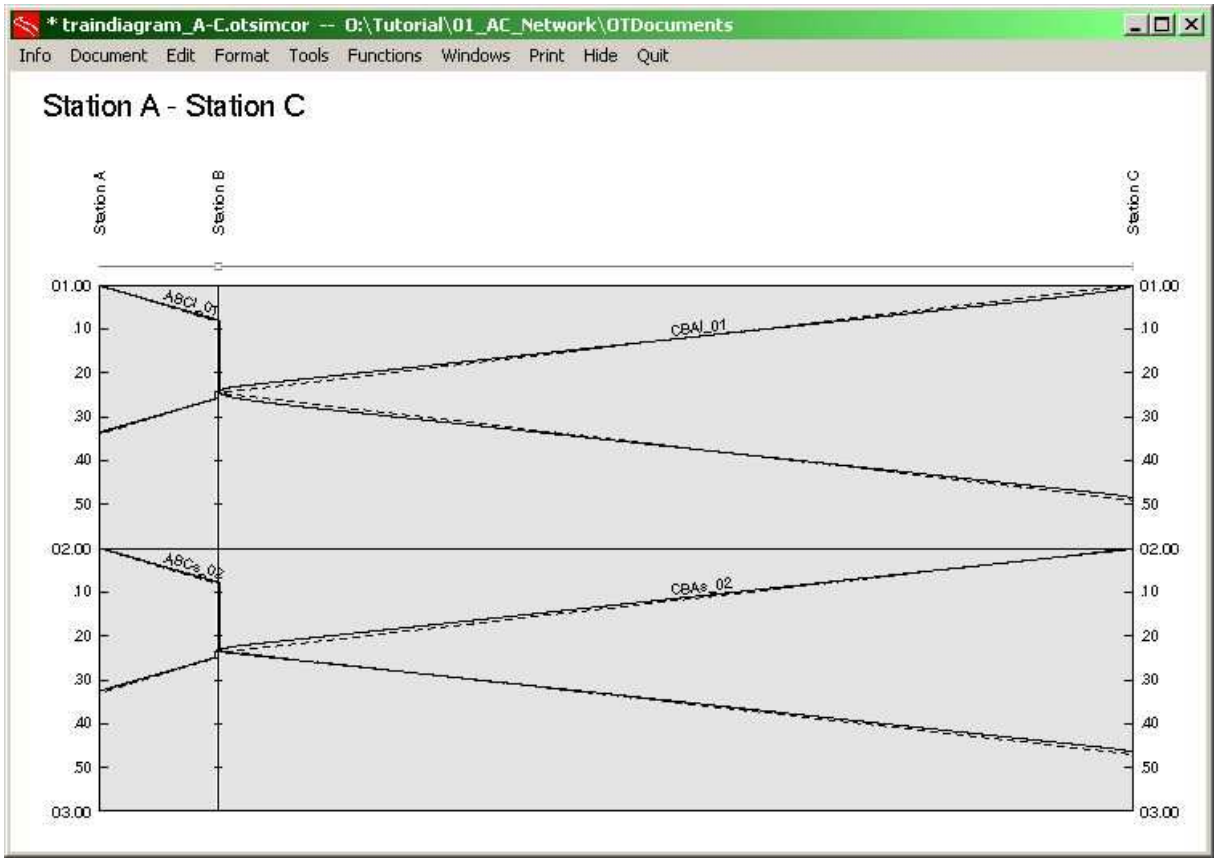


Figure 47 The train diagram for all four trains from Station A to Station C.

6.2.1.2 OpenPowerNet

As described before we need to set the properties in the GUI to configure the OpenPowerNet modules, for details see the GUI Help System. In our Tutorial we use the default properties and do not need to change anything.

The following chapters describe in detail the configuration of the Engine-File, Project-File and the Switch-File. As we do not use energy storage we do not need to configure a TypDef-File.

6.2.1.2.1 Engine-File

First of all we need to create a new XML-File and to specify the schema. Read chapter 7.8 for how to get the schema directory.

The default Engine-File is:

```
<?xml version="1.0" encoding="UTF-8"?>
<railml xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="D:\Usr\OpenPowerNet-
1.2.2\plugins\de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm\schemas\rollingstock.xsd">
  <rollingstock rollingstockID="" version=""/>
</railml>
```

Now we need to configure the engine according to our needs and corresponding to OpenTrack, see chapter 6.2.1.1. In addition to OpenTrack we need to configure the tractive and braking efficiency as well as the engine auxiliary power.

```
<railml xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="D:\Usr\OpenPowerNet-
1.2.2\plugins\de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm\schemas\rollingstock.xsd">
  <rollingstock rollingstockID="" version="110">
    <vehicles>
      <vehicle length="25" bruttoWeight="75" vehicleID="Engine1" speed="250">
        <engine>
          <propulsion supply="AC 25kV 50Hz" transmission="electric" engine="electric"
power="5560" maxTractEffort="250" totalTractEfficiency="90" totalBrakeEfficiency="90">
            <auxSupply typeStr="all" constPower="100"/>
          </propulsion>
        </engine>
      </vehicle>
    </vehicles>
  </rollingstock>
</railml>
```

As we have a very simple model of the engine the Engine-File is very short.

6.2.1.2.2 Project-File

The Project-File of our example is a bit more complex as the Engine-File. As for any Project-File we will configure the Engine- and Switch-File used, the Engine model and the electrical model.

First of all we need to create a new XML-File and to specify the schema. The latest schema can be found in plugin `de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm/schemas/OpenPowerNet.xsd`.

At the beginning we will configure the general simulation data.

```
<OpenPowerNet
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="D:\Usr\OpenPowerNet-1.2.2\plugins\de.bahntechnik.dd.opn.bin_
x.x.x_JJJJMMDDhhmm\schemas\OpenPowerNet.xsd"
name="Tutorial AC Network"
comment="This is a comment for a specific simulation."
maxIterations="1000"
maxFailedIterations="100"
odbcDsn="pscresults"
record2DB="true"
record2DB_Dump="false"
recordComputation2DB="false"
simulationStart_s="3600"
rstFile="D:\OPN_Projects\Tutorial\01_AC_Network\OPNData\Engine-File.xml">
```

Besides the name of the project and a comment set the allowed maximum iterations to 1000, the allowed failed iterations to 100 so the simulation will not abort in case iterations for some time steps fail. Time steps fail in case a network is overburden. As we want to write the simulation data directly into the database we need to set a ODBC DSN, that we want to record data but not into a dump file and that we do not want to record computation data. The recording of the simulation results shall start with the first course at 01:00 therfore we set the simulation start time to 3600 seconds. Furthermore we need to set the Engine-File just configured in the previous chapter.

The next step is to configure the engine model.

```
<ATM>
  <Vehicles>
    <Vehicle eddyCurrentBrake="false" engineID="Engine1">
      <Propulsion
supply="AC 25kV 50Hz"
engine="electric"
tractiveCurrentLimitation="none"
brakeCurrentLimitation="none"
useAuxPower="true"
fourQuadrantChopperPhi="none"
regenerativeBrake="none"
tractiveEffort="maxPower/maxTractEffort">
        <MeanEfficiency/>
      </Propulsion>
    </Vehicle>
  </Vehicles>
  <Options tolerance_A="0.1" maxIterations="1000" record2DB="true"/>
</ATM>
```

Note the green data has to correspond to OpenTrack and Engine-File. Our engine will not use eddy current brake, has no tractive or brake current limitation, uses auxiliary power, has no model for power factor as attribute `fourQuadrantChopperPhi` is set to `none`. The engine also has no regenerative bake and the tractive effort model is defined by maximum power and maximum tractive effort. The efficiency of the engine shall be modelled as mean efficiency. As we want to record data to the database set the simulation option for module ATM. For the internal ATM iteration we need to define the maximum allowed current tolerance between the iteration steps and a maximum number of allowed iterations.

After the definition of engines we will define the electrical network. The electrical network shall have two substations. One is at km 5+00 and the other at km 80+000. Each substation has one transformer, one feeder from busbar to the contact wire and one to the rails for the return current. We will define a messenger wire, a contact wire and two rails for each track. The model shall also contain the connectors between the messenger wire and contact wire as well as between the rails. Furthermore we will define a conductor modelling the earth. The origin of the cross section ordinates is defined in the middle of track “1” at a height of the rails.

Let’s start to define the network model step by step. First the network parameter:

```
<Network
name="A-C"
use="true"
voltage_kV="25"
frequency_Hz="50"
recordVoltage="true"
recordCurrent="true">
```

We have to set a network name and to tell OpenPowerNet that we want to use this network in the simulation. As we want to record voltages and currents we have to set the last two attributes of the above XML snippet to `true`.

Next is to define a line, explanations added as black bold text into the XML snippet:

```
<Lines recordCurrent="false+sub" recordVoltage="false+sub">
As we don't want to record voltages for each node and current for each conductor and connector
we set both attributes to "false+sub".
  <Line name="A" maxSliceDistance_km="0.5">
The line name has to correspond with our OpenTrack infrastructure and the maximum slice
distance shall be 500m. While defining the electrical network consider the magnetic coupling
is always calculated only between conductors of the same line!
    <Conductors>
Now conductors for track "1" follow.
      <Conductor type="MessengerWire">
        <StartPosition condName="MW" trackID="1" km="0"/> This conductor starts at km 0+000.
        <ToProperty toPos_km="85.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0" y_m="6.9"/>
The end of the conductor is at the end of the track at km 85+400. The equivalent radius,
resistance at 20°C and temperature coefficient shall be as defined. The messenger wire is
located in the middle of track "1" in a height of 6.9m.
      </Conductor>
      <Conductor type="ContactWire">
        <StartPosition condName="CW" trackID="1" km="0"/>
        <ToProperty toPos_km="85.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="0" y_m="5.3"/>
Same as above except the height of the contact wire is set to 5.3m so we have a system height
of 1.6m.
      </Conductor>
      <Conductor type="Rail">
        <StartPosition condName="RL" trackID="1" km="0"/> The left rail.
        <ToProperty toPos_km="85.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-0.75" y_m="0"/>
Note the horizontal (x) position and the equivalent radius of the rail.
      </Conductor>
      <Conductor type="Rail">
        <StartPosition condName="RR" trackID="1" km="0"/> The right rail.
        <ToProperty toPos_km="85.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0.75" y_m="0"/>
      </Conductor>
Now conductors for track "2" follow.
      <Conductor type="MessengerWire">
        <StartPosition condName="MW" trackID="2" km="9.750"/>
        <ToProperty toPos_km="10.250" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10" y_m="6.9"/>
Note the start and end of the wire.
      </Conductor>
      <Conductor type="ContactWire">
        <StartPosition condName="CW" trackID="2" km="9.750"/>
        <ToProperty toPos_km="10.250" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="10" y_m="5.3"/>
      </Conductor>
      <Conductor type="Rail">
        <StartPosition condName="RL" trackID="2" km="9.750"/>
        <ToProperty toPos_km="10.250" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="9.25" y_m="0"/>
      </Conductor>
      <Conductor type="Rail">
        <StartPosition condName="RR" trackID="2" km="9.750"/>
        <ToProperty toPos_km="10.250" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10.75" y_m="0"/>
      </Conductor>
      <Conductor type="Earth">
The earth is modelled as a virtual conductor far away from the tracks along the whole line.
        <StartPosition condName="E" trackID="1" km="0"/>
        <ToProperty toPos_km="85.4" equivalentRadius_mm="450000" r20_Ohm_km="0.0393"
temperature_GradCelsius="20" temperatureCoefficient="0" x_m="0" y_m="-450.0"/>
      </Conductor>
    </Conductors>
Now we define all the connectors of the slices.
    <ConnectorSlices>
      <ConnectorSlice name="dropper, track 1" firstPos_km="0" lastPos_km="85.4"
maxDistance_km="0.25">
This slice defines the connectors modelling the electrical connection between the messenger
and contact wire for track "1" every 250m along the whole track.
        <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
```

```
          <ConductorFrom condName="MW" trackID="1"/>
          <ConductorTo condName="CW" trackID="1"/>
        </Connector>
      </ConnectorSlice>
      <ConnectorSlice name="dropper, track 2" firstPos_km="9.750" lastPos_km="10.250"
maxDistance_km="0.25"> This slice defines the same as above for track “2”.
        <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
          <ConductorFrom condName="MW" trackID="2"/>
          <ConductorTo condName="CW" trackID="2"/>
        </Connector>
      </ConnectorSlice>
      <ConnectorSlice name="rail connector, track 1" firstPos_km="0" lastPos_km="85.4"
maxDistance_km="0.25"> As the rails are connected we define a slice with connectors between
both rails of track “1” every 250m along the whole track.
        <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
          <ConductorFrom condName="RL" trackID="1"/>
          <ConductorTo condName="RR" trackID="1"/>
        </Connector>
      </ConnectorSlice>
      <ConnectorSlice name="rail connector, track 2" firstPos_km="9.750" lastPos_km="10.250"
maxDistance_km="0.25"> And the same as above for track “2”.
        <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
          <ConductorFrom condName="RL" trackID="2"/>
          <ConductorTo condName="RR" trackID="2"/>
        </Connector>
      </ConnectorSlice>
    </ConnectorSlices>
Now we have to define the leakage of the rails to earth.
    <Leakages>
      <Leakage firstPos_km="0" lastPos_km="85.4" yReal_S_km="0.1" yImag_S_km="0">
        <ConductorFrom condName="RL" trackID="1"/>
        <ConductorTo condName="E" trackID="1"/>
      </Leakage>
      <Leakage firstPos_km="0" lastPos_km="85.4" yReal_S_km="0.1" yImag_S_km="0">
        <ConductorFrom condName="RR" trackID="1"/>
        <ConductorTo condName="E" trackID="1"/>
      </Leakage>
      <Leakage firstPos_km="9.750" lastPos_km="10.250" yReal_S_km="0.1" yImag_S_km="0">
        <ConductorFrom condName="RL" trackID="2"/>
        <ConductorTo condName="E" trackID="1"/>
      </Leakage>
      <Leakage firstPos_km="9.750" lastPos_km="10.250" yReal_S_km="0.1" yImag_S_km="0">
        <ConductorFrom condName="RR" trackID="2"/>
        <ConductorTo condName="E" trackID="1"/>
      </Leakage>
    </Leakages>
  </Line>
</Lines>
```

To model the electrical connection between the two tracks we have two ways to do so. First we could define a slice or second we could define connectors between lines or the same line. In our example we will use the second way. The electrical model will be the same. These are just two different ways to define the same connectors.

The following XML snippet defines the electrical connection between track “1” and “2”:

```
<Connectors recordCurrent="false+sub" recordVoltage="false+sub">
As we don’t want to record voltages for each node and current for each connector we set both
attributes to “false+sub”.
The 4 connectors for messenger wire, contact wire and both rails at the BEGINNING of track “1”
follow.
  <Connector name="MW track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="MW" lineID="A" trackID="1" km="9.750"/>
    <ConductorTo condName="MW" lineID="A" trackID="2" km="9.750"/>
  </Connector>
  <Connector name="CW track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="CW" lineID="A" trackID="1" km="9.750"/>
    <ConductorTo condName="CW" lineID="A" trackID="2" km="9.750"/>
  </Connector>
  <Connector name="RL track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="RL" lineID="A" trackID="1" km="9.750"/>
```

```
    <ConductorTo condName="RL" lineID="A" trackID="2" km="9.750"/>
  </Connector>
  <Connector name="RR track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="RR" lineID="A" trackID="1" km="9.750"/>
    <ConductorTo condName="RR" lineID="A" trackID="2" km="9.750"/>
  </Connector>
The 4 connectors for messenger wire, contact wire and both rails at the END of track “1”
follow.
  <Connector name="MW track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="MW" lineID="A" trackID="1" km="10.250"/>
    <ConductorTo condName="MW" lineID="A" trackID="2" km="10.250"/>
  </Connector>
  <Connector name="CW track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="CW" lineID="A" trackID="1" km="10.250"/>
    <ConductorTo condName="CW" lineID="A" trackID="2" km="10.250"/>
  </Connector>
  <Connector name="RL track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="RL" lineID="A" trackID="1" km="10.250"/>
    <ConductorTo condName="RL" lineID="A" trackID="2" km="10.250"/>
  </Connector>
  <Connector name="RR track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="RR" lineID="A" trackID="1" km="10.250"/>
    <ConductorTo condName="RR" lineID="A" trackID="2" km="10.250"/>
  </Connector>
</Connectors>
```

Now we have already defined the electrical network along the line. In the next step we have to define the substations, one at km 5+000 and one far away at km 80+000.

```
<Substations>
This is the substation at km 5+000.
  <Substation name="TSS_5">
    <TwoWindingTransformer The characteristic of the two winding transformer shall be as
defined by the attributes.
name="T1"
nomPower_MVA="10"
nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="27.5"
noLoadLosses_kW="6.5"
loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7"
noLoadCurrent_A="0.06">
      <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0"> The connection from the
transformer to the OSC busbar is defined with this element.
        <Switch name="TSS_5_T1_OCS" defaultState="close"/> This connection shall have a switch
to enable us to disconnect the transformer during the failure scenario.
      </OCSBB>
      <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0"> The connection to the rail
busbar including switch.
        <Switch name="TSS_5_T1_Rails" defaultState="close"/>
      </RailsBB>
    </TwoWindingTransformer>
Below is the definition of the busbars and the feeder cables from the busbars to the line.
    <Busbars>
      <OCSBB bbName="OCS_BB">
        <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="CW" lineID="A" trackID="1" km="5"/>
        </Connector>
      </OCSBB>
      <RailsBB bbName="Rails_BB">
        <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="RR" lineID="A" trackID="1" km="5"/>
        </Connector>
      </RailsBB>
    </Busbars>
  </Substation>
Below is the substation at km 80+000 same as the one at km 5+000.
  <Substation name="TSS_80">
    <TwoWindingTransformer name="T1" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="27.5" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
      <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
```

```
        <Switch name="TSS_80_T1_OCS" defaultState="close"/>
      </OCSBB>
      <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Switch name="TSS_80_T1_Rails" defaultState="close"/>
      </RailsBB>
    </TwoWindingTransformer>
    <Busbars>
      <OCSBB bbName="OCS_BB">
        <Connector name="TSS_80_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="CW" lineID="A" trackID="1" km="80"/>
        </Connector>
      </OCSBB>
      <RailsBB bbName="Rails_BB">
        <Connector name="TSS_80_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="RR" lineID="A" trackID="1" km="80"/>
        </Connector>
      </RailsBB>
    </Busbars>
  </Substation>
</Substations>
```

Now only two things are left before we have completed the Project-File. One is to define the earthing point and the other is to set some options for the PSC.

The definition of the earthing point is very simple:

```
<Earth condName="E" lineID="A" trackID="1" km="0"/>
```

And the options for module PSC are as well very simple:

```
<Options
tolerance_grad="0.001" The maximum allowed tolerance of the engine current angle between the
iteration inside the PSC.
maxCurrentAngleIteration="100" The maximum allowed iteration to achieve the value specified
above.
tolerance_V="0.1" The maximum allowed tolerance of the node voltage between the iteration of
ATM and PSC.
tolerance_A="0.1" The maximum allowed tolerance of the source currents between the iteration
of ATM and PSC.
maxIncreaseCount="500" The maximum allowed number of increasing voltage tolerance between ATM
and PSC iteration steps.
discreteTrains="true" The courses should be inserted at the slices and the current shall not
be distributed to both neighbouring slices.
evenlyDistributedTractionReturnCurrent="true"/>The traction current shall be evenly
distributed to both rails.
```

Now we have done the configuration of the Project-File. To check for failures and to visualise what we have done we will use the PSC Viewer, see 3.4. The PSC Viewer creates a graphical representation of the electrical network using nodes, conductors, connectors and substations. For questions regarding the PSC Viewer consult the GUI Help System. A diagram snippet is shown in Figure 48.

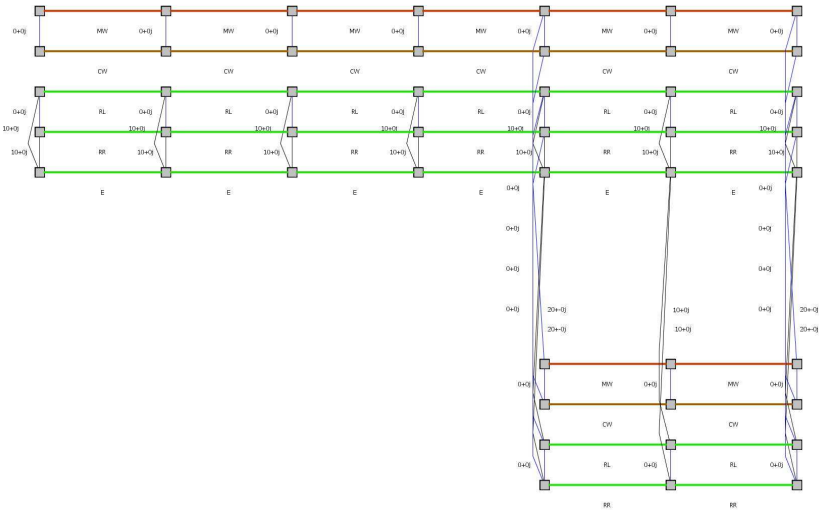


Figure 48 A snippet of the electrical network at Station B with siding in the PSC Viewer diagram.

6.2.1.2.3 Switch-File

As we later also want to simulate a failure scenario besides the default configuration we have to prepare a Switch-File. This file enables us to disconnect a transformer at a specific time by opening the switches between the transformer and the busbar.

As for the two XML-Files before we need to set the schema. The latest schema can be found in plugin `de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm/schemas/ADE.xsd`.

For this example we define to disconnect the transformer in substation at km 80+000 from 01:05:00 until 01:22:00.

```
<?xml version="1.0" encoding="UTF-8"?>
<ADE xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="D:\Usr\OpenPowerNet-
1.2.2\plugins\de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm\schemas\ADE.xsd">
  <TPD>
    <SwitchSetting>
      <Switch state="open" time="01:05:00" name="TSS_80_T1_OCS"/>
      <Switch state="open" time="01:05:00" name="TSS_80_T1_Rails"/>
      <Switch state="close" time="01:22:00" name="TSS_80_T1_OCS"/>
      <Switch state="close" time="01:22:00" name="TSS_80_T1_Rails"/>
    </SwitchSetting>
  </TPD>
</ADE>
```

6.2.2 Simulation

For the simulation it is advised to backup the database in case you want to keep old simulation data and then to create a new empty database via the GUI, just select `create new database` from the OpenPowerNet menu.

Next is to start the OpenPowerNet modules via the GUI. Select the Project-File and then `Start OpenPowerNet` from the context menu, see Figure 49.

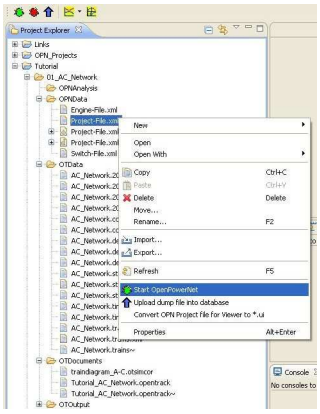


Figure 49 Start OpenPowerNet by selecting the Project-File and using the context menu.

When using the GUI for the first time you should arrange the views as described in the GUI Help System at `OpenPowerNet User Interface User Guide > Usage > Start & Stop OpenPowerNet`. Then you will have 3 separate console views, one for each module.

For the default configuration we run the simulation using the files as described above. Start all modules via the GUI, make sure the option to use OpenPowerNet in OpenTrack is set and start the simulation.

6.2.3 Analysis

6.2.3.1 Default configuration

For a quick overview we will use the delivered Excel-Files. To get a feeling of the minimum voltage we will use the file EngineAll.xls. This file is available via menu `OpenPowerNet > Excel tools > All Engines`. As the file is quite big be patient until the file is open and then select the simulation and update the data from the database into the Excel-File, see also Figure 31. You can see the line voltage and pantograph current versus the time in Figure 50. We see the no load voltage is 27.5kV and the minimum line voltage at pantograph position is about 26.4kV at 01:26:00. Furthermore we see the pantograph current does not exceed 250A.

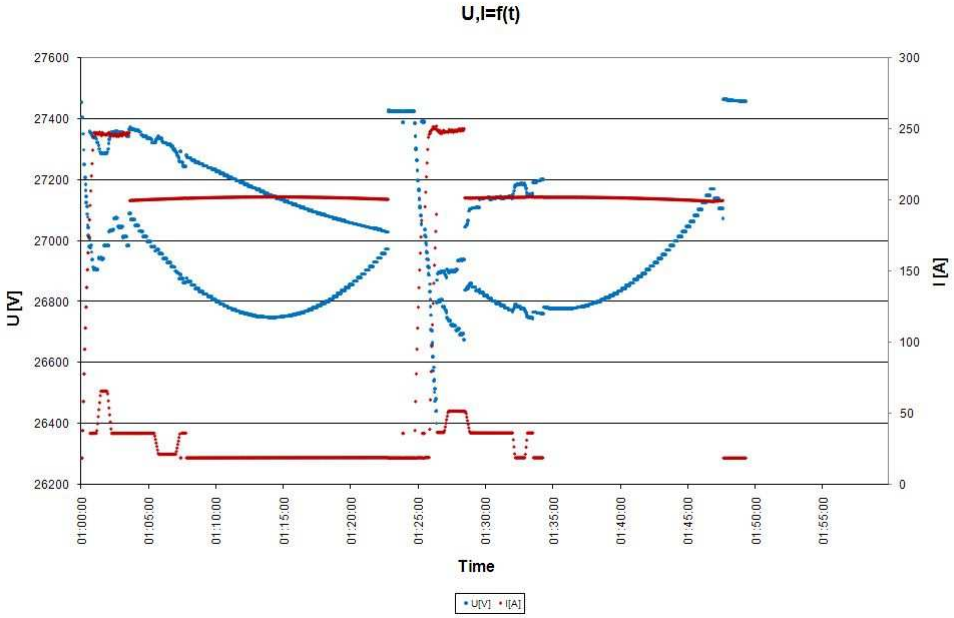


Figure 50 The line voltage and pantograph current versus time for all courses.

To see the location of the minimum line voltage at pantograph position we use the diagram in sheet “U=f(s)”, see Figure 51. This diagram shows the minimum voltages at km 12+500 and also very well the location of substation TSS_80 by the local voltage maxima at km 80+000.

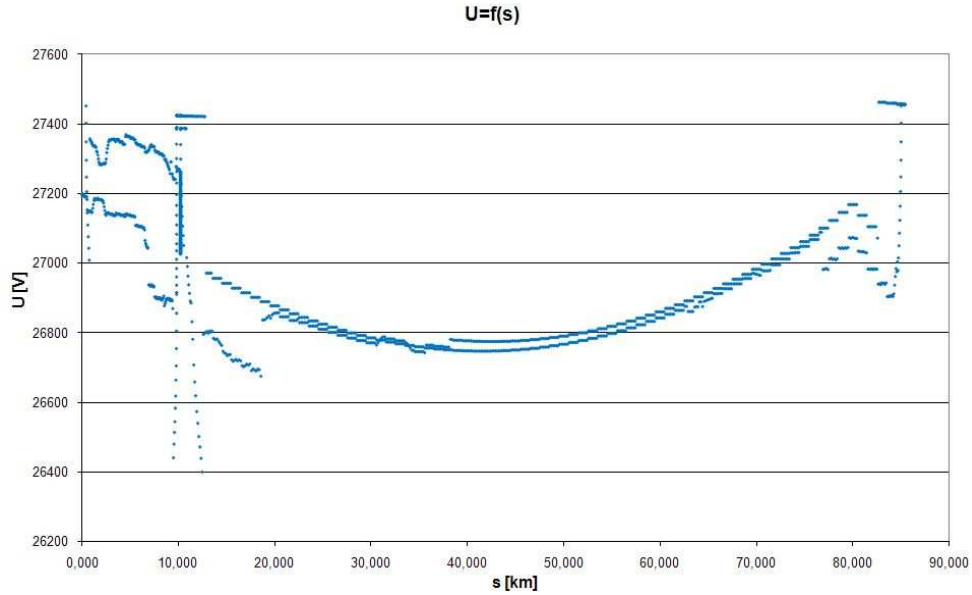


Figure 51 The line voltage at pantograph versus chainage for all courses.

Next we will use the Excel-File Engine.xls. This is available at menu `OpenPowerNet > Excel tools > One Engine`. This file provides diagrams of the pantograph current and voltage versus time and location. Very interesting is also the tractive effort versus the location. As an example we will use the course ABCl_01 and sheet F=f(s), see Figure 52.

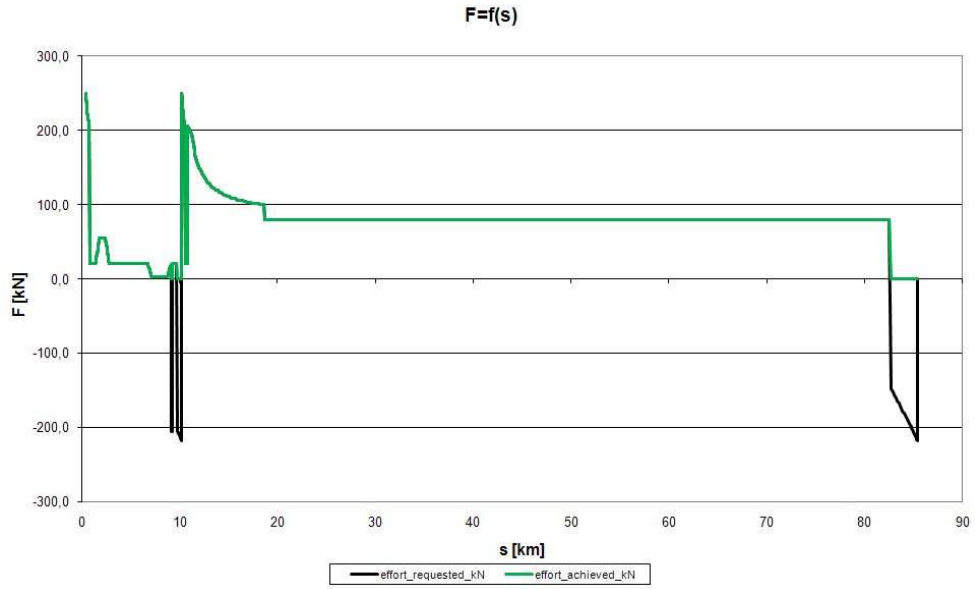


Figure 52 The requested and achieved effort of course ABCl_01 for the default configuration.

The achieved effort corresponds to the requested effort for positive effort requests. The achieved effort while braking is 0.0kN because our engine has no recovery braking. We also see the changes in effort requests caused be the varying gradients. From km 1+400 to km 2+400 the gradient is 10‰ which causes a raising effort and from km 6+750 to km 8+750 we have the adverse effect for a gradient of -5‰. The course ABCl_01 has an auxiliary power of 520kW. For the correct calculation of the efficiency we have to insert these value in cell W:2 in sheet SELECTION. After we have done so we will see the efficiency is at any time as expected 90% constantly, like in the engine configuration.

Furthermore we may have a look at the mechanical and electrical power of the course ABCl_01.

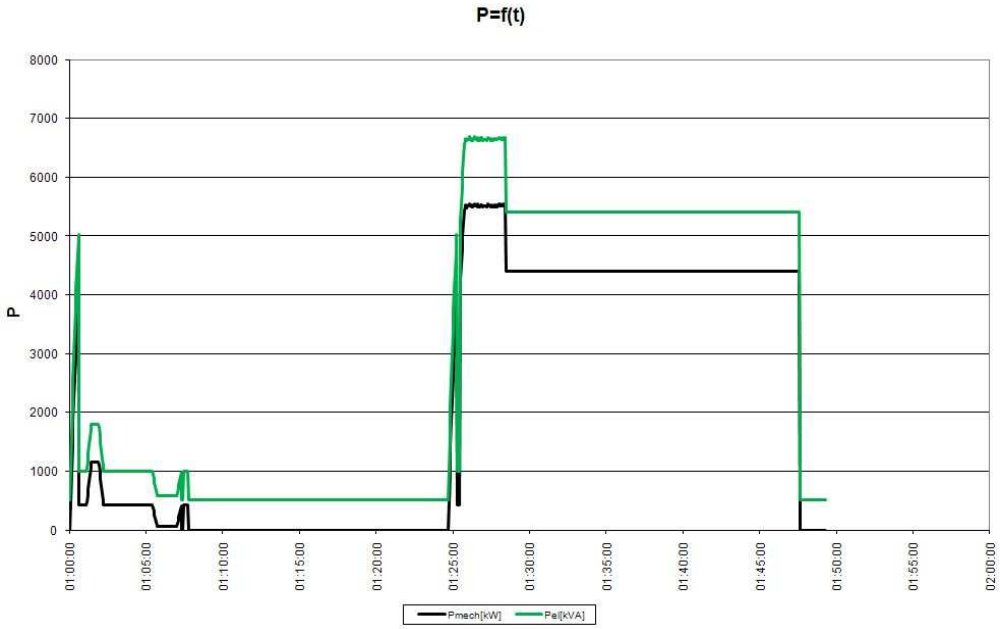


Figure 53 The mechanical and electrical power of the course ABCl_01.

In this diagram the effect of the gradients can be seen again between 01:01:00 and 01:07:00.

The course is waiting for about 15min in Station B. We can see this in the diagram where the mechanical power is 0kN. At this time we have only the auxiliary power demand of 520kW.

Besides the courses the substations are very interesting to analyse. For this we use Excel-File PowerSupply.xls with the prepared diagrams for I=f(t), U=f(t), P=f(t) and E=f(t). This file is available from the menu via `OpenPowerNet > Excel tools > One Power Supply`. First we will analyse the substation TSS_5 at km 5+000. In the Excel-File we have to select the substation, transformer, feeder and busbar voltages, see Figure 54 for details.

	1			
Simulation	001 02.06.2009 9:31:38 Tutorial AC Network		**Simulation Time**	0:05:05
	1			
Network	A-C		**Time Step**	1,0
	1			
Substation	TSS_5		TSS_5	
	1		07:00:00 =	0,2916667
Trafo	T1			
	4			
I in Feeder to	busbar OCS_BB			
	1			
first U	OCS_BB			
	2			
second U	Rails_BB			

Figure 54 The selection of power supply for substation TSS_5.

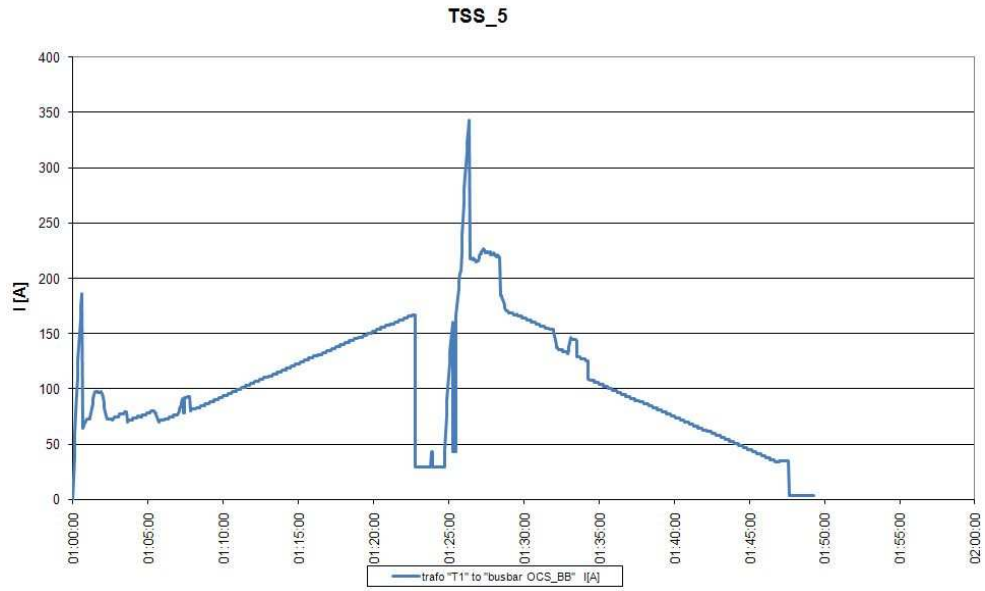


Figure 55 The current from transformer T1 to the OCS busbar in substation TSS_5.

In the diagram above we see that the current does not exceed 350A and we have no current between 01:50:00 and 02:00:00 as we have no courses at this time. We can also see the higher current in hour 01 compared to hour 02. This is caused by the longer trains in hour 01 and short trains in hour 02.

Figure 56 The voltage between OCS and Rails busbar at TSS_5.

In this diagram we see the voltage between the OCS and Rails busbar. We see very well the no load voltage of 27.5kV and voltage drops to about 26.65kV. This is still above the nominal voltage of 25kV. The different characteristic of the voltage caused by the long and short trains mentioned for Figure 55 can also be seen here.

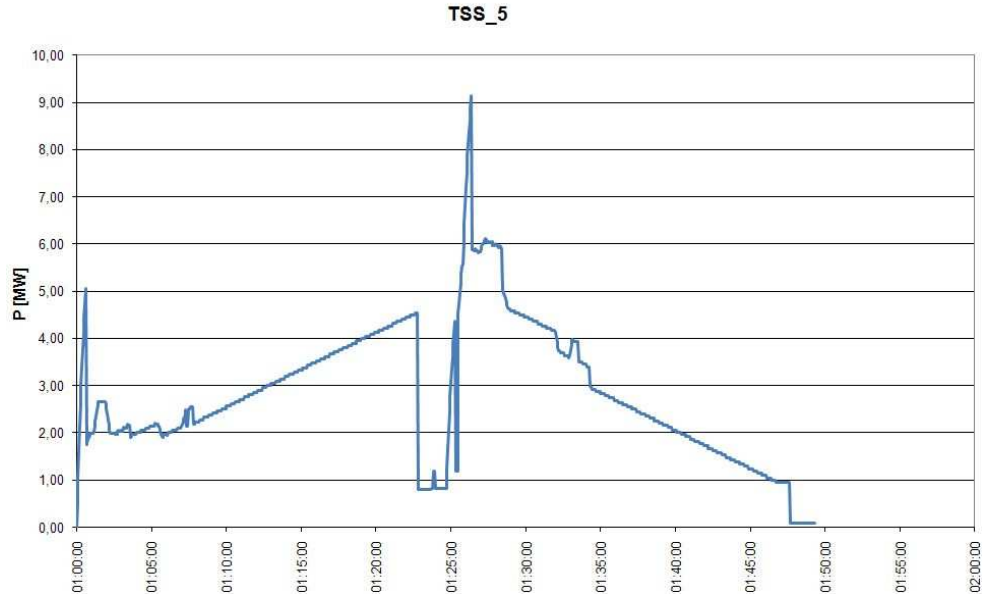


Figure 57 Power demand of the transformer in substation TSS_5.

This diagram shows the power demand of transformer T1 in substation TSS_5 at km 5+000. Same as in the two diagrams before we see very well the difference in the characteristic for the long and the short trains.

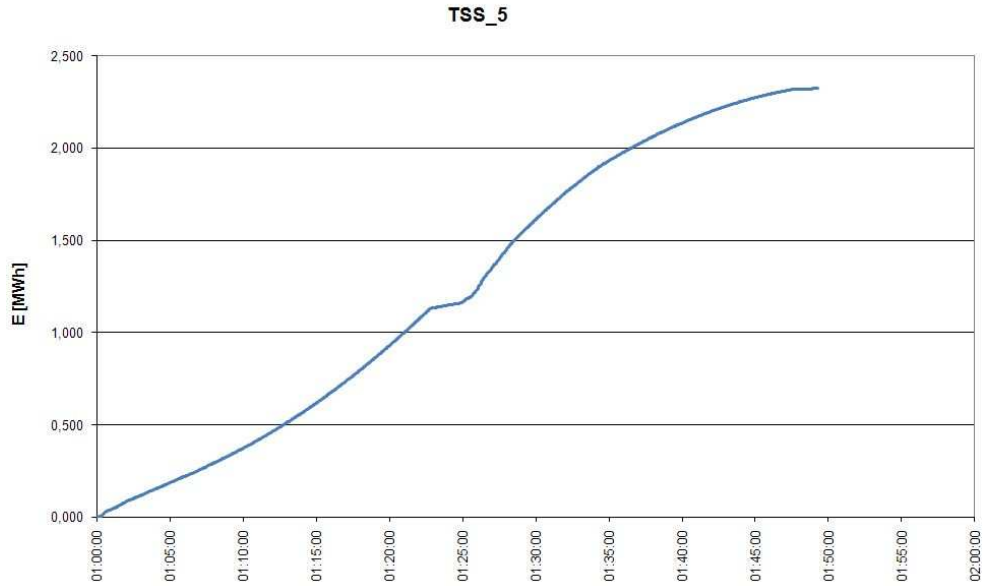


Figure 58 Provided energy by the transformer in substation TSS_5.

The diagram above shows the energy versus time. We see clearly that there is no energy consumption between 01:50:00 and 02:00:00. We see also a steeper flank of the curve in hour 01 because of the higher energy consumption of the long train compared with the short train in hour 02.

6.2.3.2 Short circuit

Usually it is interesting to calculate the short circuit currents. This is done in OpenPowerNet with a special engine model. To evaluate the results we will use the Excel-Files PowerSupply.xls (`OpenPowerNet > Excel Tools > One Power Supply`) and PowerSupply2.xls (`OpenPowerNet > Excel Tools > Compare Two Power Supplies`). The second file provides diagrams for two substations versus time.

To match the time easily with a location we want to run the course with constant speed of 36km/h respective 10m/s. In this way it is easy to match the time with the location. In OpenTrack we need to set the speed limit of all edges to 36km/h for speed type A. Then we create a new course with name `short circuit` and the itinerary from Station A to Station C via track “1”, set the speed type to A and the entry speed to 36km/h, see Figure 59. Now we have a course with constant speed along the whole line from Station A to Station C.

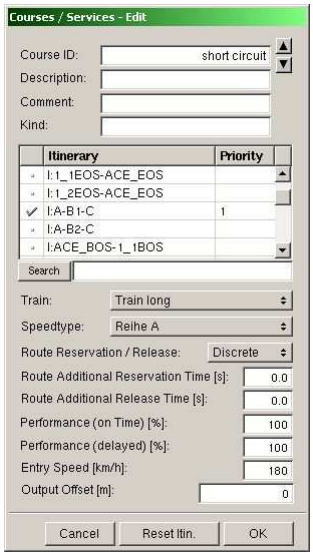


Figure 59 Short circuit course configuration in OpenTrack.

In the OpenPowerNet Project-File we need to add a new attribute to the engine.

```
<Vehicle eddyCurrentBrake="false" engineID="Engine1">
  <Propulsion
engine="electric"
supply="AC 25kV 50Hz"
shortCircuitEngine="true" The new attribute to simulate short circuits. Other attributes will
be ignored by OpenPowerNet.
brakeCurrentLimitation="none"
tractiveCurrentLimitation="none"
useAuxPower="true"
fourQuadrantChopperPhi="none"
regenerativeBrake="none"
tractiveEffort="maxPower/maxTractEffort">
    <MeanEfficiency/>
  </Propulsion>
</Vehicle>
```

For the short circuit simulation we usually need the short circuit current at the substation for the protection settings. In this tutorial we use only TSS_5 and power off TSS_80 by opening the switches at transformer T1 in TSS_80. We only need to change the default state for the switches `TSS_80_T1_OCS` and `TSS_80_T1_Rails` from `close` to `open`.

After we have done all the amendments in the Project-File for the short circuit simulation we run again the simulation only with course `short circuit`.

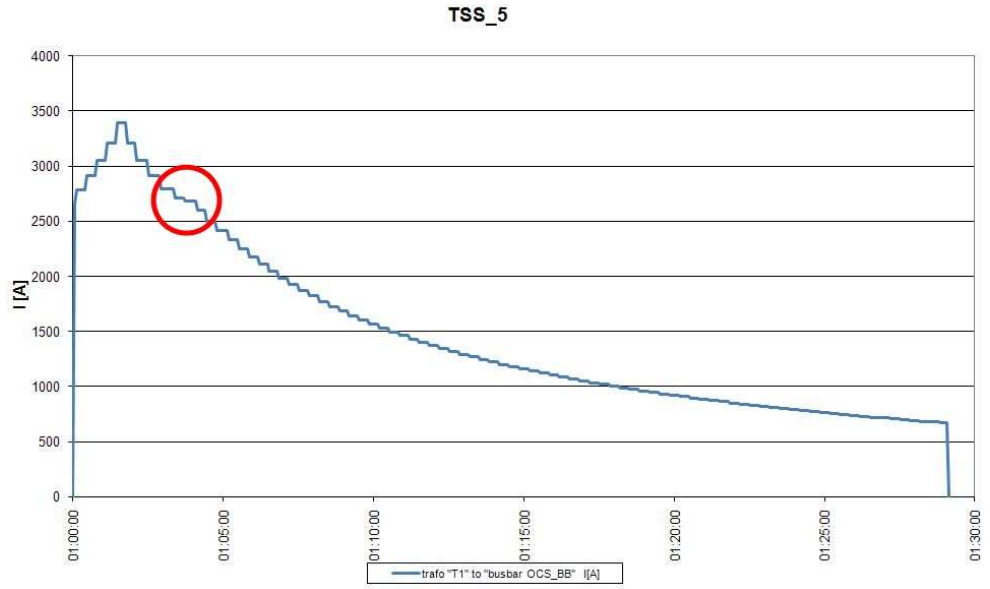


Figure 60 The short circuit current of substation TSS_5 at km 5+000 versus time. The red circle marks the Station B with siding.

From the diagram above we can see the minimum short circuit current between contact wire and rails of substation TSS_5 is about 670A compared to a maximum engine current of 250A from the default scenario, see Figure 50.

To check the minimum short circuit current we do the same simulation as before but with both substations. Therefore we need to set the default state for the switches `TSS_80_T1_OCS` and `TSS_80_T1_Rails` to `close` and run the simulation again. The minimum current is about 2300A, see Figure 61.

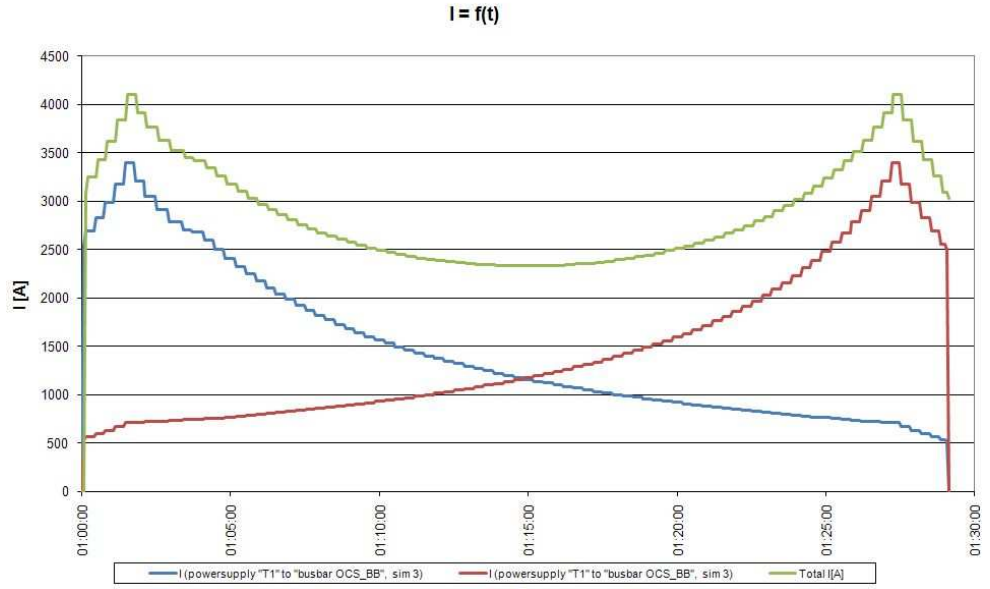


Figure 61 The short circuit current with both substations.

6.2.3.3 Constant current

To check the pantograph voltage in a network we want to draw a constant current along the whole line. This can be done easily by OpenPowerNet. Just add one course in OpenTrack, e.g. with name “constant current”, use the itinerary from Station A via track “1” in Station B to Station C and add a timetable. As we have seen in the previous simulation the maximum short circuit current is about 2300A so we will use a lower current of 2000A for this simulation. Otherwise the network is overburden.

Then add one attribute to the Project-File:

```
<Vehicle eddyCurrentBrake="false" engineID="Engine1">
  <Propulsion
engine="electric"
supply="AC 25kV 50Hz"
constantCurrent_A="2000" This is the new attribute. Other attributes will be ignored by
OpenPowerNet.
brakeCurrentLimitation="none"
tractiveCurrentLimitation="none"
useAuxPower="true"
fourQuadrantChopperPhi="none"
regenerativeBrake="none"
tractiveEffort="maxPower/maxTractEffort">
    <MeanEfficiency/>
  </Propulsion>
</Vehicle>
```

and set a proper comment in the Project-File to identify this simulation while analysing the data.

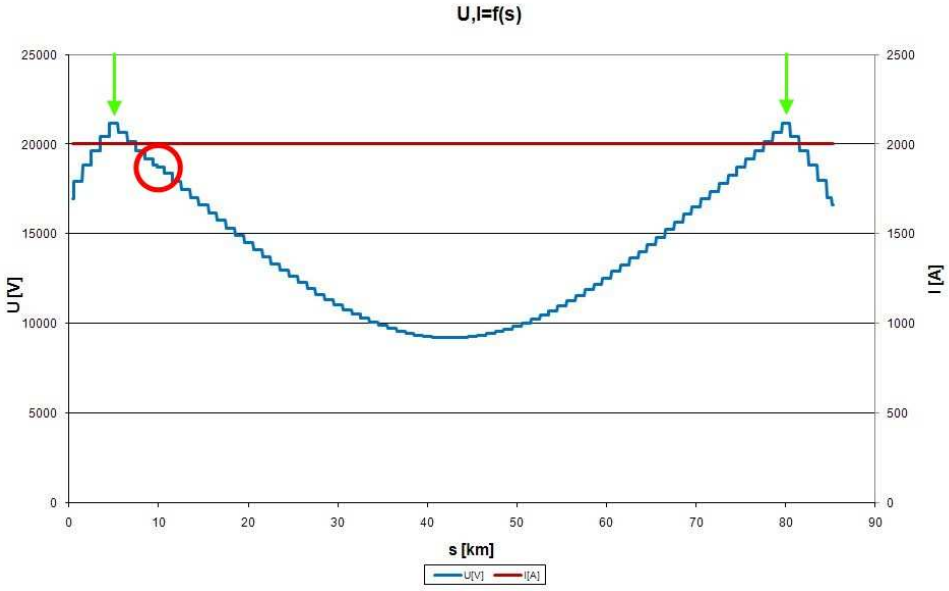


Figure 62 The voltage and current along the line for the constant current of 2000A. The green arrows point to the substation positions. The red circle is the Station B with siding. Therefore the voltage drop in this station is less compared to the open line between the stations with only one track.

The diagram above is from the file Engine.xls. The current is of course constant and has the value specified in the Project-File. The voltage is calculated according to the electrical network.

6.2.3.4 Failure scenario

As described in chapter 4.2.3.4 we want to disconnect the transformer in TSS_80 from 01:05:00 to 01:22:00 and have a power supply during that time only from TSS_5.

In OpenTrack we will use all courses from the default configuration. For OpenPowerNet we need to adapt the project file slightly. We only need to specify the Switch-File and to give the simulation a proper comment, see XML snippet below.

```
<OpenPowerNet xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="D:\Usr\OpenPowerNet-
1.2.2\plugins\de.bahntechnik.dd.opn.bin_x.x.x_JJJJMMDDhhmm\schemas\OpenPowerNet.xsd"
name="Tutorial AC Network"
comment="failure scenario" This is a comment for the failure scenario.
maxIterations="1000"
maxFailedIterations="100"
dbUser="opndbusr"
dbPasswd="lmarqst3"
odbcDsn="pscresults"
record2DB="true"
record2DB_Dump="false"
recordComputation2DB="false"
rstFile="D:\OPN_Projects\Tutorial\01_AC_Network\OPNData\Engine-File.xml"
switchStateFile="D:\OPN_Projects\Tutorial\01_AC_Network\OPNData\Switch-File.xml" The added
Switch-File.
simulationStart_s="3600">
```

Do not forget to change the constant current engine in the Project-File back to the default configuration!

After the simulation has finished we should check substation TSS_80. For this we will use PowerSupply2.xls and Engine2.xls.

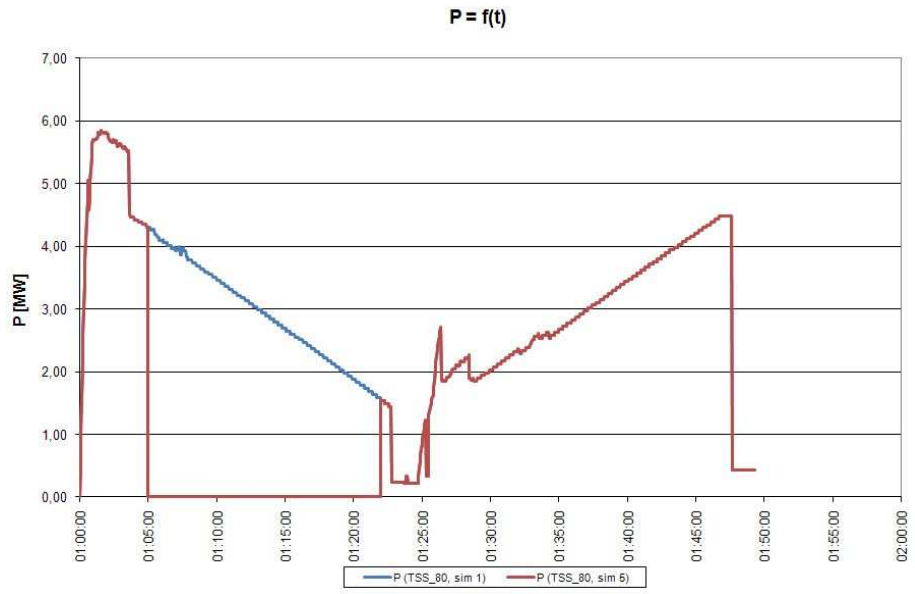


Figure 63 The diagram compares the power supplies of the transformer in TSS_80 between the default configuration (P1) and the failure scenario (P2).

In the diagram above we can see that the transformer in TSS_80 had been switched off from 01:05:00 to 01:22:00 as it was defined in the Switch-File.

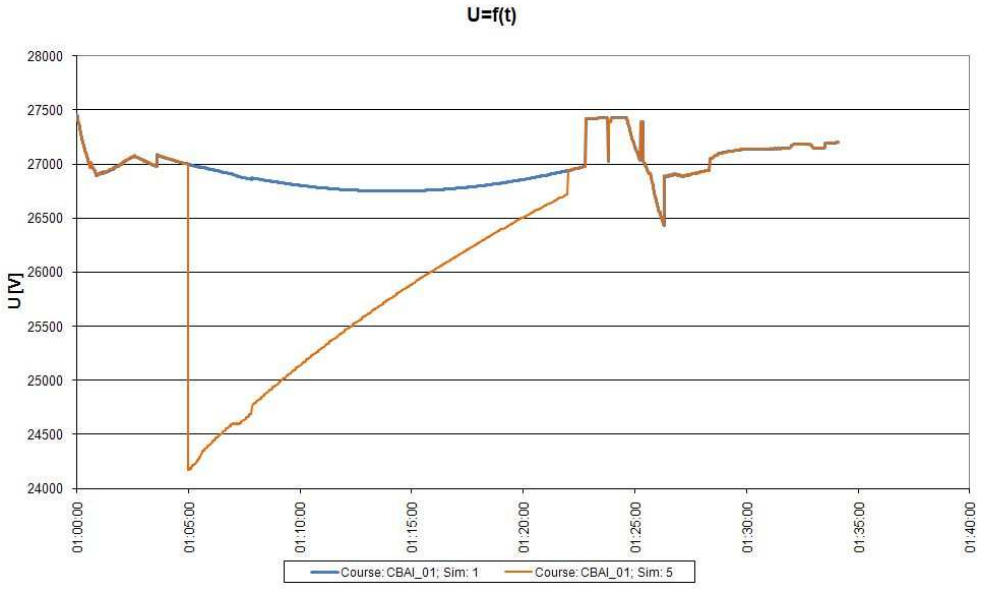


Figure 64 This diagram compares the line voltage for course CBAI_01 of the default configuration (Sim 1) and the failure scenario (Sim 5) versus the time.

We can see very well the difference of the line voltage at the pantograph for both simulations.

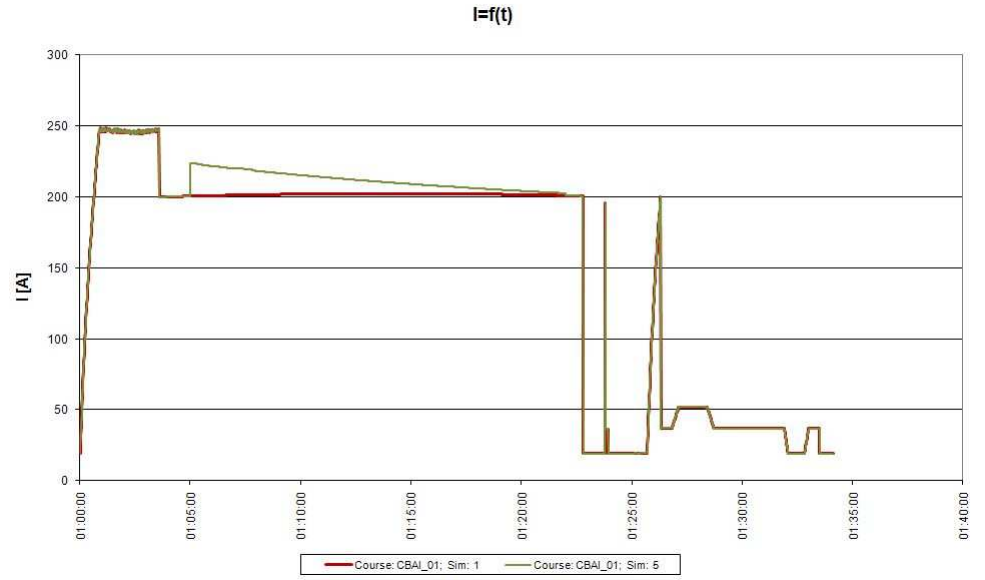


Figure 65 This diagram compares the current for course CBAI_01 of the default configuration (Sim 1) and the failure scenario (Sim 5) versus the time.

The diagram above shows the power off effect of substation TSS_80 for the current used by course CBAI_01. As the course uses the same power in both simulations the current rises with dropping line voltage.

6.3 2AC Network tutorial

In this tutorial we will use the same OpenTrack infrastructure as for the AC Network tutorial and change only the existing Project-File for a 2AC electrical network. To keep the file of the previous tutorial we create a copy of the Project-File.

6.3.1 Configuration

6.3.1.1 OpenTrack

We will use the same OpenTrack data as for the AC tutorial described in chapter 6.2.1.1.

6.3.1.2 OpenPowerNet

6.3.1.2.1 Engine-File

We will use the same engine as for AC and therefore we do not need to change the Engine-File.

6.3.1.2.2 Project-File

For the 2AC system we change the transformer in TSS_5 to a three winding transformer and change substation TSS_80 to autotransformer station ATS_80. For the negative phase we add a negative feeder from km 5+000 to km 80+000.

First we add the negative feeder:

```
<Conductor type="NegativeFeeder">
  <StartPosition condName="NF" trackID="1" km="5"/>
The beginning of the negative feeder at km 5+000 and the name NF.
  <ToProperty
toPos_km="80" The end of the negative feeder at km 80+000.
equivalentRadius_mm="8.4" Following the characteristic
r20_Ohm_km="0.1188"
temperature_GradCelsius="20"
temperatureCoefficient="0.004"
x_m="-4" and the cross section position.
y_m="9"/>
</Conductor>
```

Second we change the transformer in TSS_5 to a three winding transformer:

```
<Substation name="TSS_5">
  <ThreeWindingTransformer This is the new three winding transformer.
name="T1"
nomPower_MVA="10"
nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="55"
noLoadLosses_kW="6.5"
loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7"
noLoadCurrent_A="0.06">
    <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="TSS_5_T1_OCS" defaultState="close"/>
    </OCSBB>
    <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="TSS_5_T1_Rails" defaultState="close"/>
    </RailsBB>
    <NegativeFeederBB bbName="NF_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
The new negative feeder busbar.
      <Switch name="TSS_5_T1_NF" defaultState="close"/>
    </NegativeFeederBB>
  </ThreeWindingTransformer>
  <Busbars>
    <OCSBB bbName="OCS_BB">
      <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
```

```
        <Position condName="CW" lineID="A" trackID="1" km="5"/>
      </Connector>
    </OCSBB>
    <RailsBB bbName="Rails_BB">
      <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="RR" lineID="A" trackID="1" km="5"/>
      </Connector>
    </RailsBB>
    <NegativeFeederBB bbName="NF_BB">
The new feeder for the negative feeder.
      <Connector name="TSS_5_NF_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="NF" lineID="A" trackID="1" km="5"/>
      </Connector>
    </NegativeFeederBB>
  </Busbars>
</Substation>
```

Third we change TSS_80 to ATS_80 with autotransformer and busbars for OCS, rails and negative feeder:

```
<Substation name="ATS_80">
  <Autotransformer This is the autotransformer.
name="T1"
nomPower_MVA="5"
nomPrimaryVoltage_kV="55"
nomSecondaryVoltage_kV="27.5"
noLoadLosses_kW="5"
loadLosses_kW="10"
relativeShortCircuitVoltage_percent="1.8"
noLoadCurrent_A="0.2">
    <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="ATS_80_T1_OCS" defaultState="close"/>
    </OCSBB>
    <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="ATS_80_T1_Rails" defaultState="close"/>
    </RailsBB>
    <NegativeFeederBB bbName="NF_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="ATS_80_T1_NF" defaultState="close"/>
    </NegativeFeederBB>
  </Autotransformer>
  <Busbars>
    <OCSBB bbName="OCS_BB">
      <Connector name="ATS_80_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="CW" lineID="A" trackID="1" km="80"/>
      </Connector>
    </OCSBB>
    <RailsBB bbName="Rails_BB">
      <Connector name="ATS_80_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="RR" lineID="A" trackID="1" km="80"/>
      </Connector>
    </RailsBB>
    <NegativeFeederBB bbName="NF_BB">
      <Connector name="ATS_80_NF_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="NF" lineID="A" trackID="1" km="80"/>
      </Connector>
    </NegativeFeederBB>
  </Busbars>
</Substation>
```

After all this changes we check the new configuration using PSC Viewer and we will see the added negative feeder as in Figure 66.

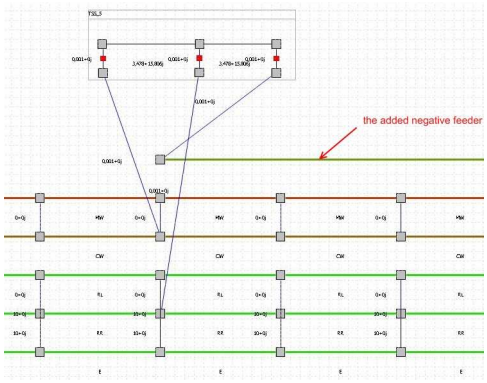


Figure 66 A snippet of the 2AC network with TSS_5 and negative feeder.

6.3.1.2.3 Switch-File

We need to adapt the Switch-File of the failure scenario simulation. First we change the switch names and second we add also the switches of the negative feeder.

```
<?xml version="1.0" encoding="UTF-8"?>
<ADE xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="D:\Usr\OpenPowerNet-
1.2.2\plugins\de.bahntechnik.dd.opn.bin_x.y.z_YYYYMMDDhhmm\schemas\ADE.xsd">
  <TPD>
    <SwitchSetting>
      <Switch state="open" time="01:05:00" name="ATS_80_T1_OCS"/>
      <Switch state="open" time="01:05:00" name="ATS_80_T1_Rails"/>
      <Switch state="open" time="01:05:00" name="ATS_80_T1_NF"/>
The open time definition of the added negative feeder switch.
      <Switch state="close" time="01:22:00" name="ATS_80_T1_OCS"/>
      <Switch state="close" time="01:22:00" name="ATS_80_T1_Rails"/>
      <Switch state="close" time="01:22:00" name="ATS_80_T1_NF"/>
The close time definition of the added negative feeder switch.
    </SwitchSetting>
  </TPD>
</ADE>
```

6.3.2 Simulation

For the description of the simulation see the AC network tutorial in chapter 6.2.2.

6.3.3 Analysis

In the following chapter we will analyse the same network configuration as we did for the AC network and compare the simulation results.

6.3.3.1 Default configuration

For the default configuration we want to compare some diagrams to see the difference between the two systems.

First we want to compare the line voltage at the pantograph. Please see Figure 51 from AC network and Figure 67 from 2AC network.

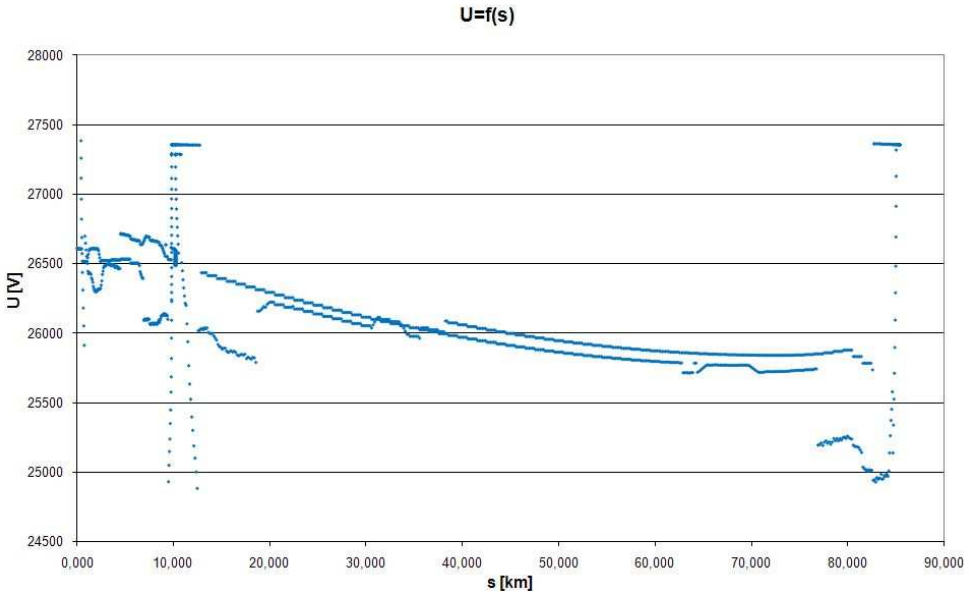


Figure 67 The line voltage at pantograph position for the default configuration of the 2AC network versus chainage.

We can see that the line voltage at the pantograph is much lower than for the AC network but still sufficient as the minimum is just below the nominal voltage.

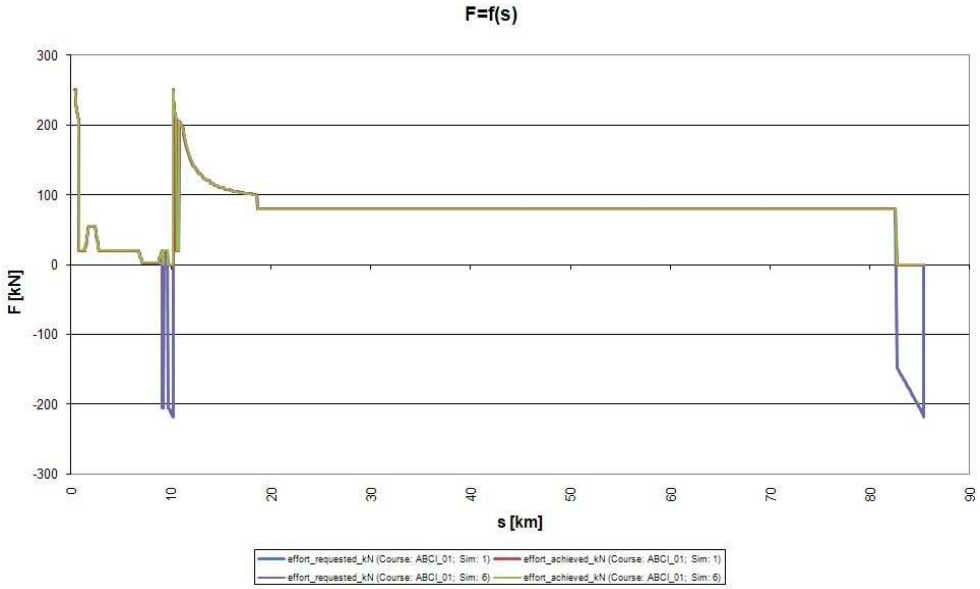


Figure 68 The requested and achieved effort for course ABCl_01 in AC network (sim 1) and 2AC network (sim 6).

All curves for our model are the same. Therefore there will be no difference in the operational simulation in OpenTrack, see Figure 68.

As there is no difference in the effort we may expect to have the same power demand for TSS_5 in both configurations.

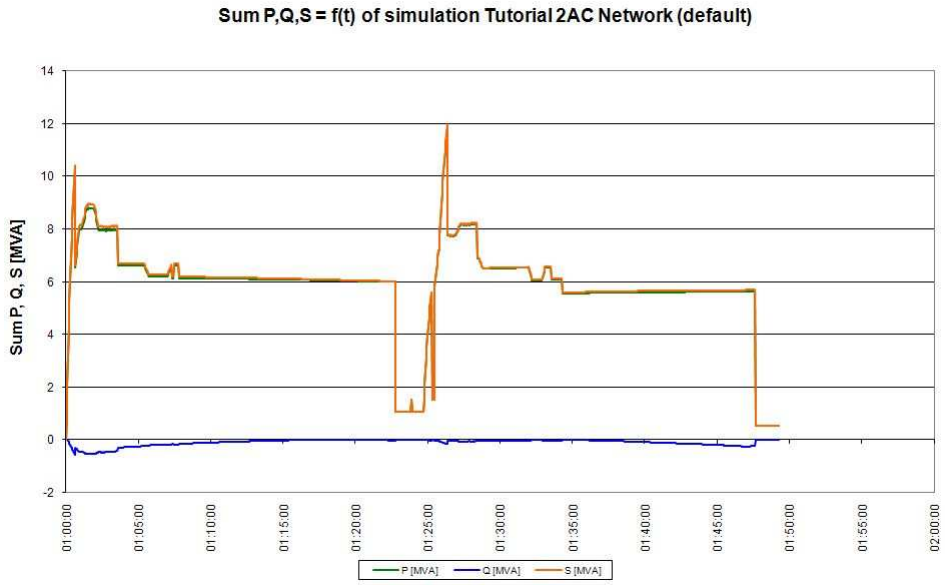


Figure 69 The power demand of substation TSS_5 for the 2AC network.

Now we will compare the power demand for the AC network in Figure 57 with Figure 69 for the 2AC network using Excel-File PowerSupply2AC.xls. We see the power demand for the 2AC network is much higher than for the AC network. This is the case because for the AC network we have two substations and for the 2AC network only one substation and one auto transformer station. Therefore TSS_5 has to supply the total power and losses in the 2AC network.

Another comparison can be done for the energy consumption. Figure 70 shows the energy consumption of the AC network provided from both substations and Figure 71 for the 2AC network provided only from TSS_5.

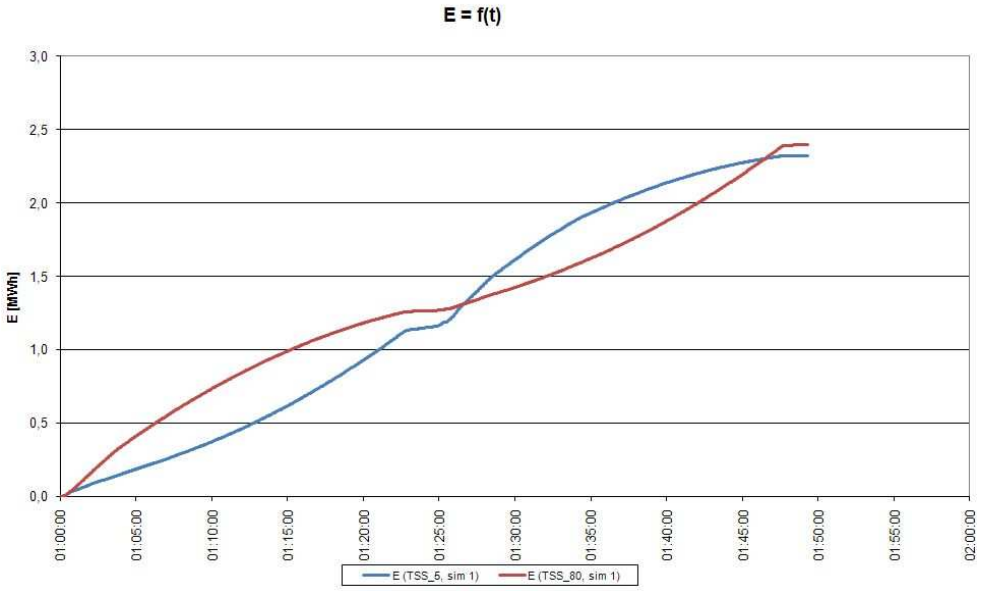


Figure 70 Energy supply from both TSS of the AC network in default configuration.

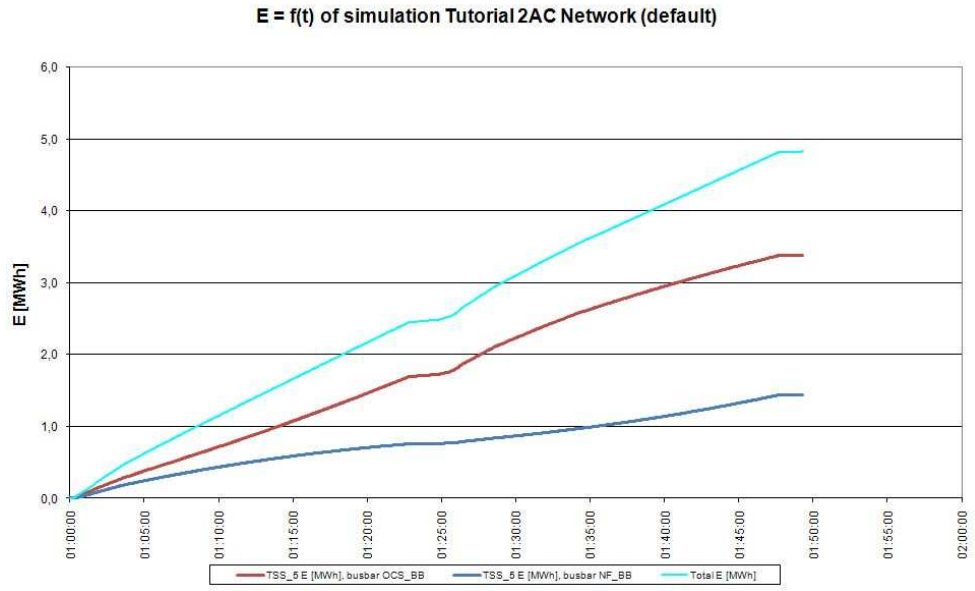


Figure 71 Energy supply from TSS_5 of the 2AC network in default configuration.

The total energy consumption of the AC network is 6.34MVA, TSS_5 supplied 3.11MVA and TSS_80 3.23MVA, compared to 6.46MVA of the 2AC network. The difference of about 2% is caused by the auto transformer losses and the higher losses caused by the higher currents due to lower line voltage.

6.3.3.2 Short circuit

For the short circuit simulation we modify the engine as described in the AC tutorial, use the course “short circuit” and run the simulation.

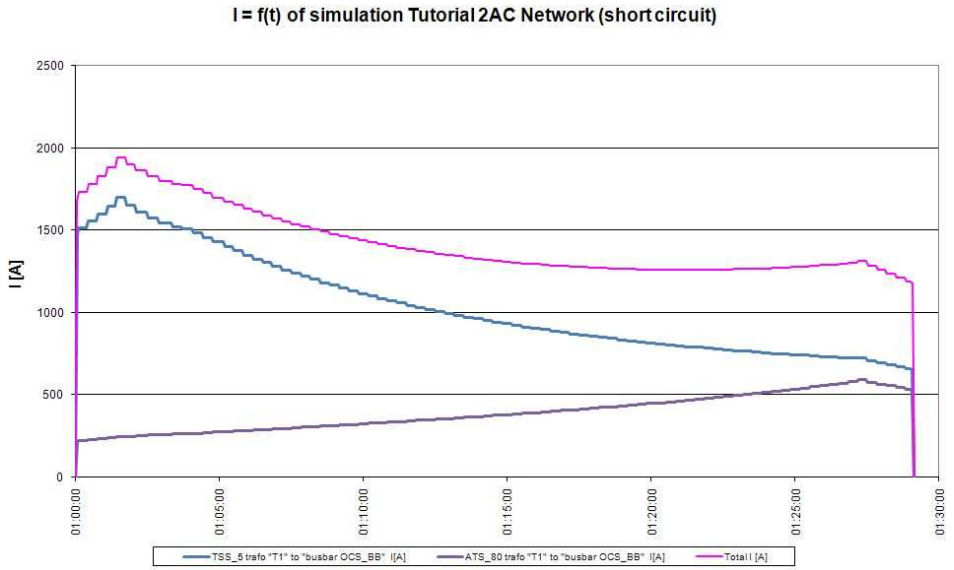


Figure 72 The short circuit current of the 2AC network. The short circuit current is the total of TSS_5 and ATS_80 current.

6.3.3.3 Constant current

From Figure 72 we can see that the minimum short circuit current is about 1200A. Therefore we will use a constant current of 1000A for the constant current simulation. We need to do the same configuration as for the AC tutorial except we have to set the current to 1000A. To be able to compare AC and 2AC configurations we will also run an additional constant current simulation with 1000A for the AC network.

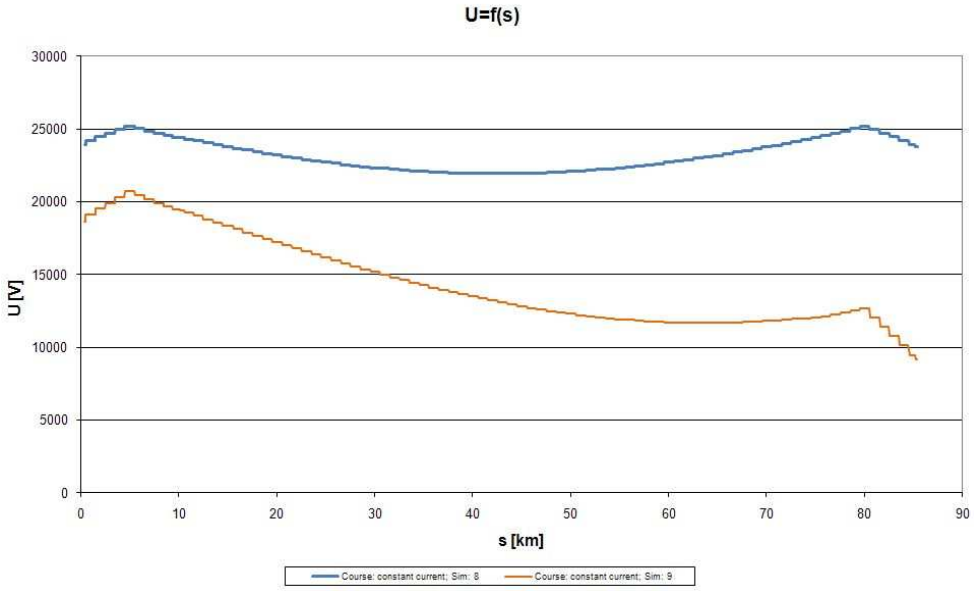


Figure 73 The constant current with 1000A causes a voltage drop down to less than 10kV at the end of the line in the 2AC network (sim 8). The AC network with a constant current of 1000A is from simulation 9.

As we can see in the diagram above the line voltage drops much more for this 2AC configuration as it does for AC.

6.3.3.4 Failure scenario

For the failure scenario the same configuration tasks as for the AC network have to be done but we need to specify the Switch-File from chapter 6.3.1.2.3.

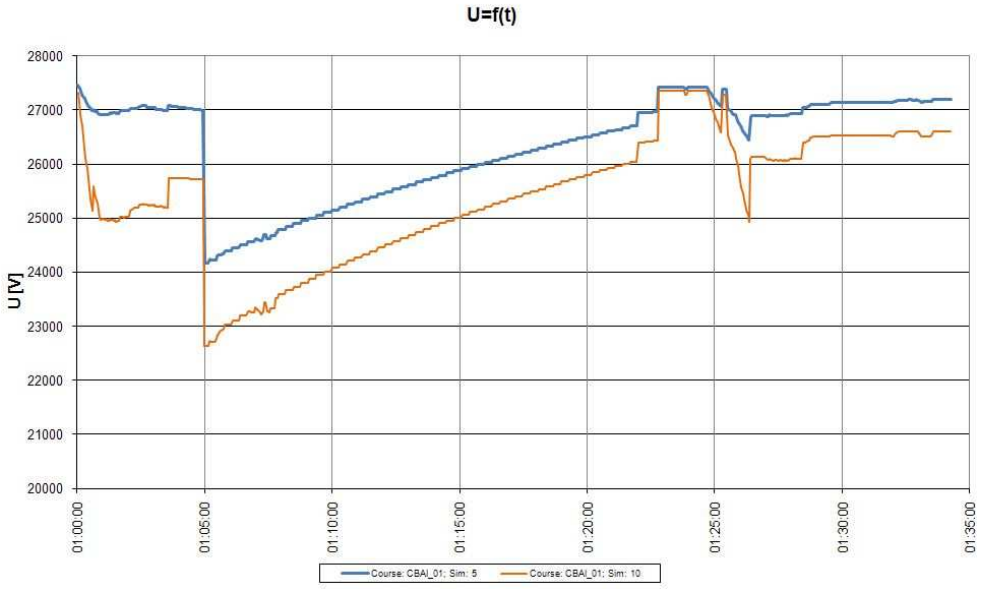


Figure 74 The failure scenario line voltage at pantograph for course CBAI_01 in AC (sim 5) and 2AC (sim 10) network.

As expected we see a voltage drop between 01:05:00 and 01:22:00 because the TSS_80 respective the ATS_80 was powered off. It is also not surprising to see a lower voltage for 2AC as we have compared the line voltage for 1000A constant current in Figure 73 and found that the lower curve belongs to the 2AC network.

6.4 DC Network tutorial

In this tutorial we will change the power supply to a 3kV DC system with two substations at the same positions as before, km 5+000 and 80+000. The negative feeder of the 2AC network will be used as line feeder and connected with the contact wire of track “1”every 250m.

We will use the same engine with 5.56MW maximum tractive power as before. The maximum power for the long train with 30kW auxiliary power per trailer and 100kW auxiliary power of the engine is 6.08MW. At nominal voltage the current will be approximately 2000A. We can expect that such a high current will cause a high voltage drop. Therefore we will use the tractive current limitation to stabilise the pantograph voltage. The current limitation shall be 0A at 0V, then linear to 2000A at 2.7kV (90% of nominal voltage) and then constant 2000A.

6.4.1 Configuration

6.4.1.1 OpenTrack

We will use the same OpenTrack data as for the AC tutorial described in chapter 6.2.1.1.

6.4.1.2 OpenPowerNet

6.4.1.2.1 Engine-File

We need to change the power supply system and add the current limitation.

As the power supply system specified for the infrastructure in OpenTrack is used to choose the correct tractive-effort-curve of the engine and we do not want to change this curve we do not need to change anything in OpenTrack but the supply system of the engine propulsion system in OpenPowerNet.

```
<propulsion
supply="DC 3000V"
transmission="electric"
engine="electric"
power="5560"
maxTractEffort="250"
totalTractEfficiency="90"
totalBrakeEfficiency="90">
  <auxSupply typeStr="all" constPower="100"/>
  <tractiveCurrentLimitation>
Below is the table of the tractive current limitation. The table defines points and the y-
value will be calculated by a linear interpolation between the points. For x-values exceeding
the highest specified x-value the y-value for the maximum x-value is used during simulation.
The same behaviour applies to x-values lower than specified.
    <valueTable xValueName="line voltage" xValueUnit="V" yValueName="current" yValueUnit="A">
      <valueLine xValue="0"> The 0V, 0A point.
        <values yValue="0"/>
      </valueLine>
      <valueLine xValue="2700"> The 2700V, 2000A point.
        <values yValue="2000"/>
      </valueLine>
    </valueTable>
  </tractiveCurrentLimitation>
</propulsion>
```

6.4.1.2.2 Project-File

As the base of this Project-File we will use the Project-File of the AC network and adapt it.

First we adapt the engine model by changing the supply and useing the tractive current limitation.

```
<Propulsion
engine="electric"
supply="DC 3000V" Change the supply system to DC 3000V.
brakeCurrentLimitation="none"
tractiveCurrentLimitation="I=f(U)" Change this value from none to I=f(U).
useAuxPower="true"
fourQuadrantChopperPhi="none"
regenerativeBrake="none"
tractiveEffort="maxPower/maxTractEffort">
  <MeanEfficiency/>
</Propulsion>
```

Next we add the line feeder as a conductor with the same characteristics as the negative feeder of the 2AC tutorial.

```
<Conductor type="Feeder"> Change the type of the conductor
  <StartPosition condName="LF" trackID="1" km="5"/> and change the name to LF.
  <ToProperty
toPos_km="80"
equivalentRadius_mm="8.4"
r20_Ohm_km="0.1188"
temperature_GradCelsius="20"
temperatureCoefficient="0.004"
x_m="-4"
y_m="9"/>
</Conductor>
```

Then we need to add the connectors every 250m from the line feeder to the contact wire of track “1”. The resistance per meter shall be the same as for the line feeder and the length shall be approximately 5m. Therefore the connector resistance is 0.594mΩ (0.1188Ω/km/1000*5m = 0.000594Ω).

```
<ConnectorSlice
```

```
name="line feeder to CW"
firstPos_km="5"
lastPos_km="80"
maxDistance_km="0.25">
  <Connector zReal_Ohm="0.000594" zImag_Ohm="0">
    <ConductorFrom condName="LF" trackID="1"/>
    <ConductorTo condName="CW" trackID="1"/>
  </Connector>
</ConnectorSlice>
```

Now we configure the substation models with DC rectifier and we use switches in the connectors from the busbars to the line. The switches will be used during the failure scenario.

```
<Substations>
  <Substation name="TSS_5">
    <Rectifier
name="R1"
internalResistance_Ohm="0.01" The internal resistance of the rectifier.
nomVoltage_kV="3.3"
The no load voltage of the rectifier shall be 10% higher than the system voltage of 3kV.
energyRecovery="false">
      <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0"/>
      <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0"/>
    </Rectifier>
    <Busbars>
      <OCSBB bbName="OCS_BB">
        <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="CW" lineID="A" trackID="1" km="5"/>
        </Connector>
        <Connector name="TSS_5_LF_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="LF" lineID="A" trackID="1" km="5"/>
        </Connector>
      </OCSBB>
      <RailsBB bbName="Rails_BB">
        <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="RR" lineID="A" trackID="1" km="5"/>
        </Connector>
      </RailsBB>
    </Busbars>
  </Substation>
  <Substation name="TSS_80">
    <Rectifier
name="R1"
internalResistance_Ohm="0.01"
nomVoltage_kV="3.3"
energyRecovery="false">
      <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0"/>
      <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0"/>
    </Rectifier>
    <Busbars>
      <OCSBB bbName="OCS_BB">
        <Connector name="TSS_80_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Switch defaultState="close" name="TSS_80_OCS"/>
          <Position condName="CW" lineID="A" trackID="1" km="80"/>
        </Connector>
        <Connector name="TSS_80_LF_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Switch defaultState="close" name="TSS_80_LF"/>
          <Position condName="LF" lineID="A" trackID="1" km="80"/>
        </Connector>
      </OCSBB>
      <RailsBB bbName="Rails_BB">
        <Connector name="TSS_80_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="RR" lineID="A" trackID="1" km="80"/>
          <Switch defaultState="close" name="TSS_80_Rails"/>
        </Connector>
      </RailsBB>
    </Busbars>
  </Substation>
</Substations>
```

6.4.1.2.3 Switch-File

We need to adapt the Switch-File of the AC tutorial for the failure scenario simulation. First we change the switch names and second we add also the switches to the line feeder.

```
<?xml version="1.0" encoding="UTF-8"?>
<ADE xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="D:\Usr\OpenPowerNet-
x.y.z\plugins\de.bahntechnik.dd.opn.bin_1.1.0.b6_200905261507\schemas\ADE.xsd">
  <TPD>
    <SwitchSetting>
      <Switch state="open" time="01:05:00" name="TSS_80_OCS"/>
      <Switch state="open" time="01:05:00" name="TSS_80_Rails"/>
      <Switch state="open" time="01:05:00" name="TSS_80_LF"/>
      <Switch state="close" time="01:22:00" name="TSS_80_OCS"/>
      <Switch state="close" time="01:22:00" name="TSS_80_Rails"/>
      <Switch state="close" time="01:22:00" name="TSS_80_LF"/>
    </SwitchSetting>
  </TPD>
</ADE>
```

6.4.2 Simulation

For the description of the simulation see the AC network tutorial in chapter 6.2.2.

6.4.3 Analysis

6.4.3.1 Default configuration

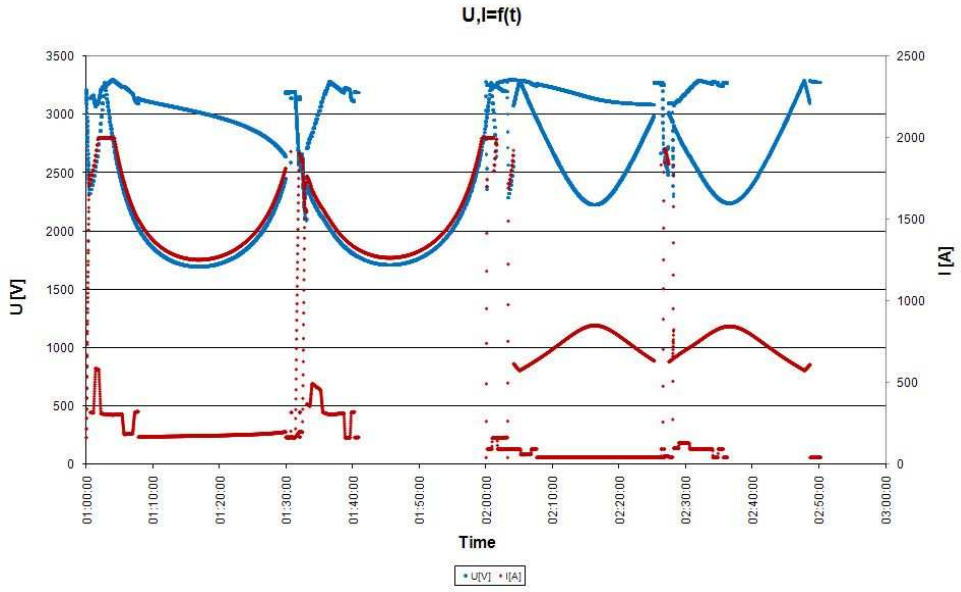


Figure 75 The pantograph line voltage and current versus time for the DC network default configuration.

In the diagram above we can see the current limitation very well in hour 01 as the current drops as well as the voltage. Usually it is as in hour 02 where the currents rise while the voltage drops to keep the constant power respective constant traction effort.

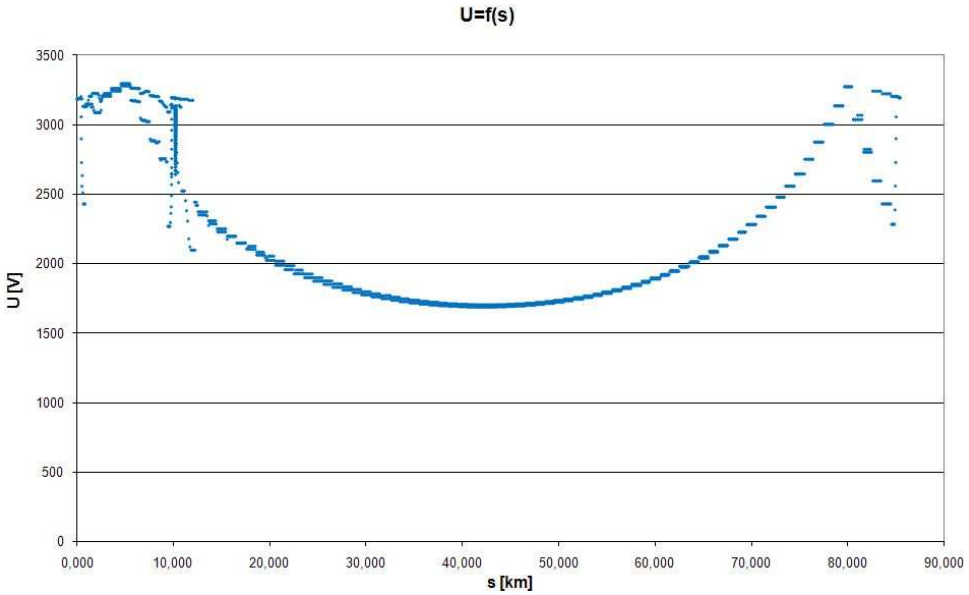


Figure 76 The line voltage at pantograph versus chainage.

As we would expect the minimum of the pantograph line voltage is in the middle between the two substations.

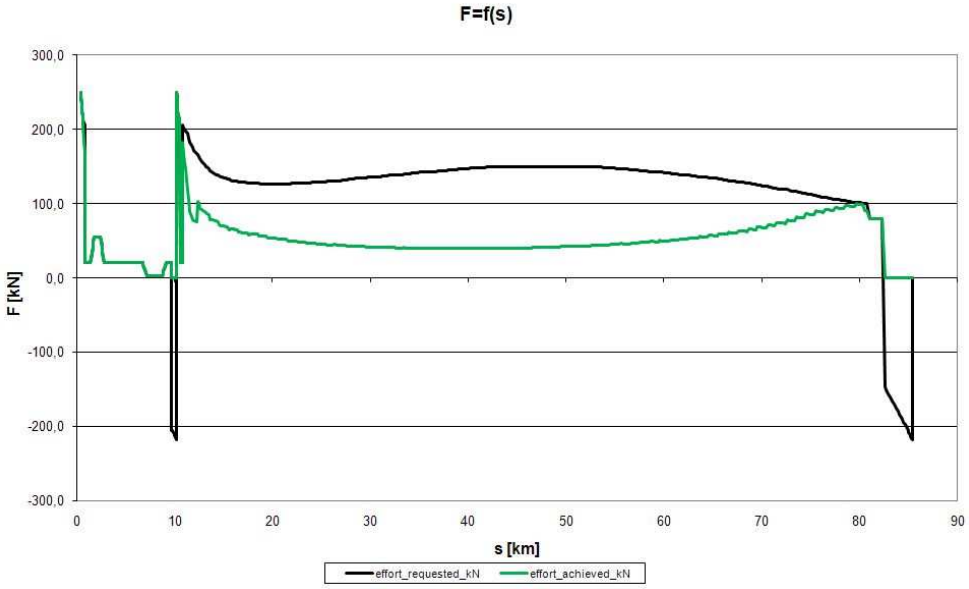


Figure 77 The requested and achieved effort of course ABCl_01 for the default configuration.

The diagram above shows the effect of the traction current limitation very clearly. If we compare the travel time of course ABCl_01 in Figure 78 we will see the effect of the lower achieved effort in a 14 minutes and 5 seconds longer travel time of this course in the DC network.

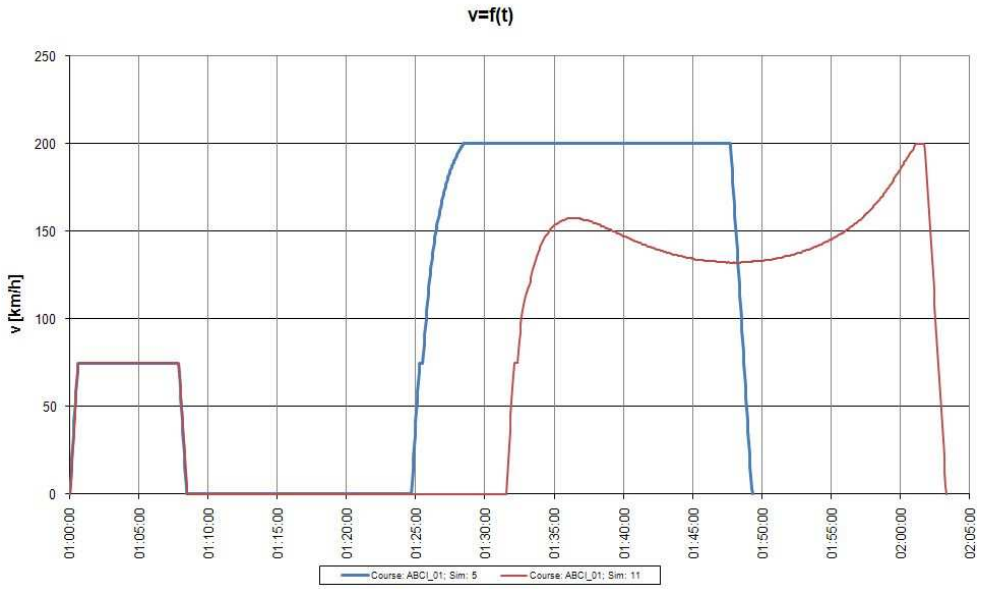


Figure 78 The speed versus time for course ABCI_01 in the AC network (sim 1) and DC network (sim 11).

6.4.3.2 Short circuit

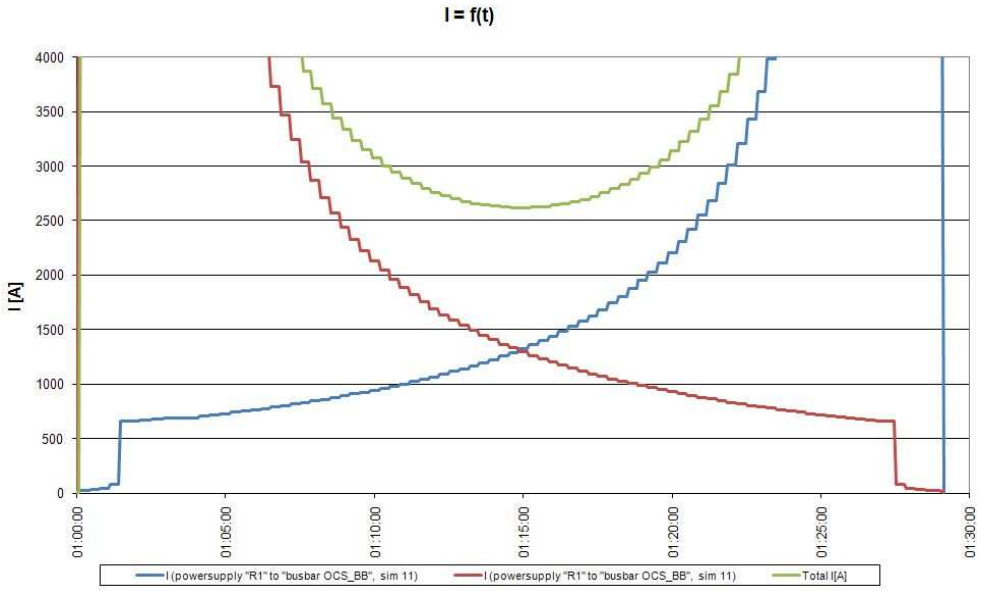


Figure 79 The short circuit simulation of the DC network.

The simulation is done as for the AC network. The y-axis is limited to 4000A as the current at the substation is very high and we are interested in the minimum short circuit current.

6.4.3.3 Constant current

As we can see in Figure 79 the minimum current is above 2500A. Therefore we will do the constant current simulation with 1000A as in the previous tutorials.

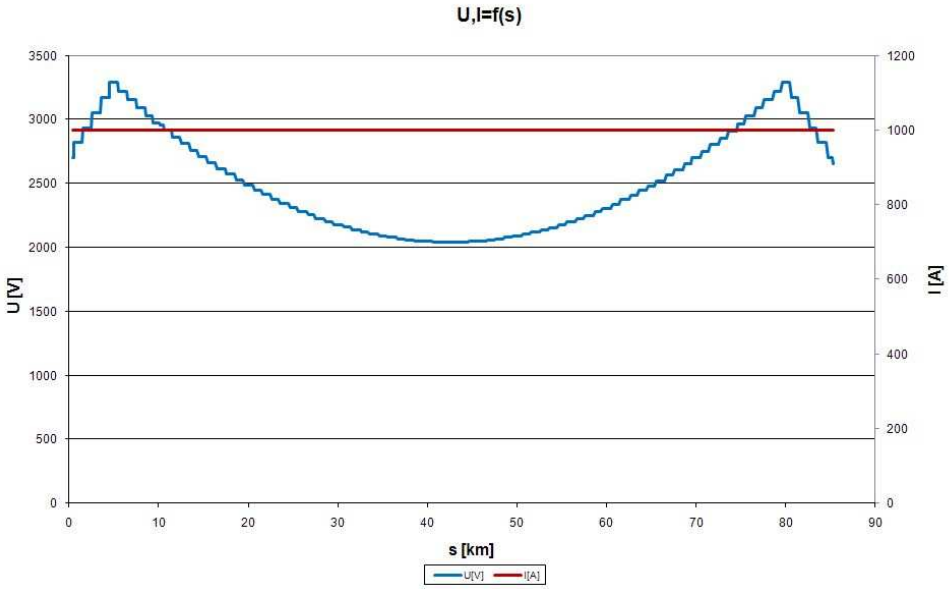


Figure 80 The voltage versus chainage of constant current simulation.

6.4.3.4 Failure scenario

See chapter 6.2.3.4 to configure the Project-File and to run the simulation. We will experience that the network is not able to cope with the failure of TSS_80. The simulation will abort because the iteration between ATM and PSC will not find a stable network state as the network is overburden.

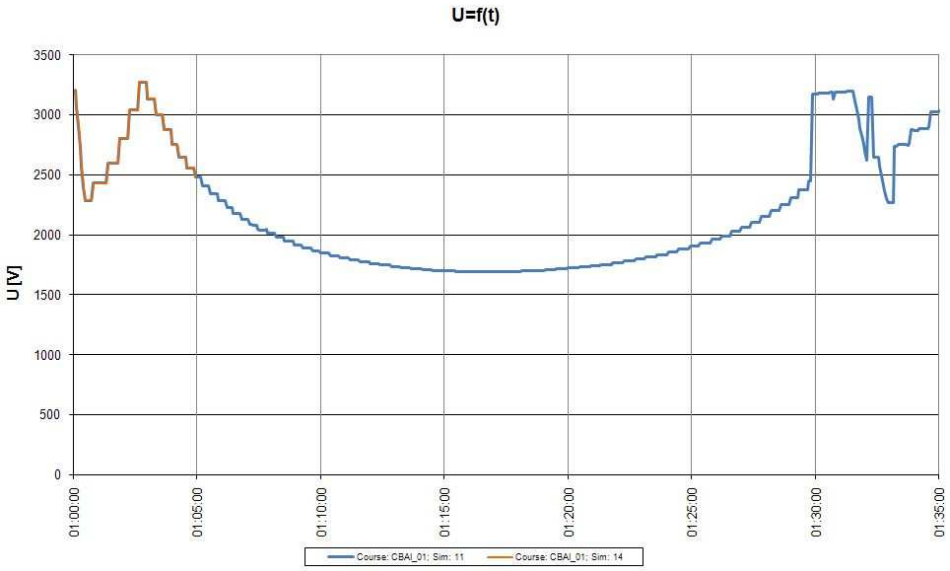


Figure 81 The line voltage for course CBAI_01 in default configuration (sim 11) and failure scenario (sim 14).

In the diagram above we can see the red curve from the failure scenario simulation. As we have configured in Project-File to allow a maximum of 100 failed iterations between ATM and PSC before the simulation terminates we see the incorrect values after 01:05:00.

6.5 DC Network with Energy Storage tutorial

In this tutorial we will add an energy storage to the DC network of the tutorial in chapter 6.4. The DC tutorial analysis shows us a significant line voltage drop. With the storage we will support the line voltage at the location with the lowest line voltage at km 45+000, see Figure 76. Furthermore we will analyse and compare two kinds of energy storage and use the courses with short trains.

6.5.1 Configuration

6.5.1.1 OpenTrack

We will use the same OpenTrack data as for the AC tutorial described in chapter 6.2.1.1.

6.5.1.2 OpenPowerNet

For OpenPowerNet we need to define an energy storage in the TypDef-File and add a substation with this energy storage at km45+000 to the Project-File. The Engine-File does not need to be changed.

6.5.1.2.1 Engine-File

We will use the same engine as for DC Network tutorial and therefore we do not need to change the Engine-File.

6.5.1.2.2 TypDef-File

First of all we need to create a new XML-File and to specify the schema. The latest schema can be found in plugin `de.bahntechnik.dd.opn.bin_1.2.2_JJJJMMDDhhmm/schemas/TypeDefs.xsd`, see chapter 7.9.

We will define two kinds of energy storage. One with 400A and one with 200A load and unload current limitation.

The energy storage shall have the following characteristic:

- Maximum load of 300MWs,
- Initial load of 300MWs,
- Losses of the energy storage of 100W,
- Internal load resistance of 5mΩ,
- Internal unload resistance of 5mΩ and
- Auxiliary power of 10kW.

The energy storage control shall have the following function:

- Maximum load current is limited to 400A, resp. 200A,
- Maximum unload current is limited to 400A, resp. 200A,
- Start loading if the line voltage is higher than 3000V,
- Stop loading if the line voltage is lower than 2999V,
- Start unload if the line voltage is lower than 2700V and

- Stop unload if the line voltage is higher than 2701V.

The XML below is the content of the TypDef-File.

```
<?xml version="1.0" encoding="UTF-8"?>
<TypeDefs xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="http://www.dd.bahntechnik.de/opn/schemas/1.1.0/b6/TypeDefs.xsd"
>
  <StorageTypes>
    <StorageType
     name="Type_400A"> The name of the energy storage used as reference in the Project-File.
      <Characteristics
       type="simple" The type of the energy storage. As we have only one it is always
"simple". Following attributes describe the characteristic of the energy storage.
       maxLoad_MWs="300"
       initialLoad_MWs="300"
       lossPower_kW="0.1"
       loadRi_Ohm="0.005"
       unloadRi_Ohm="0.005"
       auxPower1_kW="10"/>
      <Function The control function is described by the following attributes according to the
bullet points above.
       minLoadAllowUnload_MWs="0"
       loadMaxCurrent1_A="400"
       unloadMaxCurrent1_A="400"
       voltage1LoadStart_kV="3.000"
       voltage1LoadStop_kV="2.999"
       voltage1UnloadStart_kV="2.700"
       voltage1UnloadStop_kV="2.701"/>
    </StorageType>
The energy storage with 200A load and unload current limitation.
    <StorageType
     name="Type_200A"> Note the different names of the two energy storage definistions.
      <Characteristics
       type="simple"
       maxLoad_MWs="300"
       initialLoad_MWs="300"
       lossPower_kW="0.1"
       loadRi_Ohm="0.005"
       unloadRi_Ohm="0.005"
       auxPower1_kW="10"/>
      <Function
       minLoadAllowUnload_MWs="0"
       loadMaxCurrent1_A="200"
       unloadMaxCurrent1_A="200"
       voltage1LoadStart_kV="3.000"
       voltage1LoadStop_kV="2.999"
       voltage1UnloadStart_kV="2.700"
       voltage1UnloadStop_kV="2.701"/>
    </StorageType>
  </StorageTypes>
</TypeDefs>
```

6.5.1.2.3 Project-File

As the base of this Project-File we will use the Project-File of the DC network and add a substation with an energy storage at km 45+000. See the XML snippet with the substation configuration.

```
<Substation name="SS_45">
  <Busbars> The definitions of busbars and the connections to the line follow.
    <OCSBB bbName="OCS_BB">
      <Connector name="SS_45_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="CW" lineID="A" trackID="1" km="45" />
        <Switch defaultState="close" name="SS_45_OCS" />
      </Connector>
    </OCSBB>
    <RailsBB bbName="Rails_BB">
      <Connector name="SS_45_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="RR" lineID="A" trackID="1" km="45" />
        <Switch defaultState="close" name="SS_45_Rails" />
```

```
      </Connector>
    </RailsBB>
  </Busbars>
  <Storage name="S1"
   storageReference="Type_400A" This is the reference to the storage defined in the TypDef-
File.
   recordStatus="true" We want to record the status of this storage to the database.
   unlimitedLoad="false"> The storage shall not have an unlimited load.
    <BusbarFrom bbName="OCS_BB" /> The energy storage is connected to this busbar
    <BusbarTo bbName="Rails_BB" /> and this busbar.
  </Storage>
</Substation>
```

To load the TypDef-File at simulation start we need to define the attribute `typedefsFile` in the Project-File's root element `OpenPowerNet`.

```
typedefsFile="D:\OPN_Projects\Tutorial\04_Simple_Storage\OPNData\TypDef-File.xml"
```

As we want to run the short trains only we should set the simulation start time to 2:00 in the Project-File's root element `OpenPowerNet`.

```
simulationStart_s="7200"
```

6.5.2 Simulation

We will run two simulations only with the short train courses, ABCs_01 and CBAs_01. One simulation shall be with the "Type_200A" energy storage and one with the "Type_400A" energy storage. Just take care to set the energy storage reference in substation SS_45 and to give each simulation a meaningful comment.

6.5.3 Analysis

First we will compare the DC network with and without energy storage type "Type_400A". We use Engine2.xls from menu `OpenPowerNet > Excel Tools > Compare Two Engines`. The data for the network without storage is available from the DC tutorial.

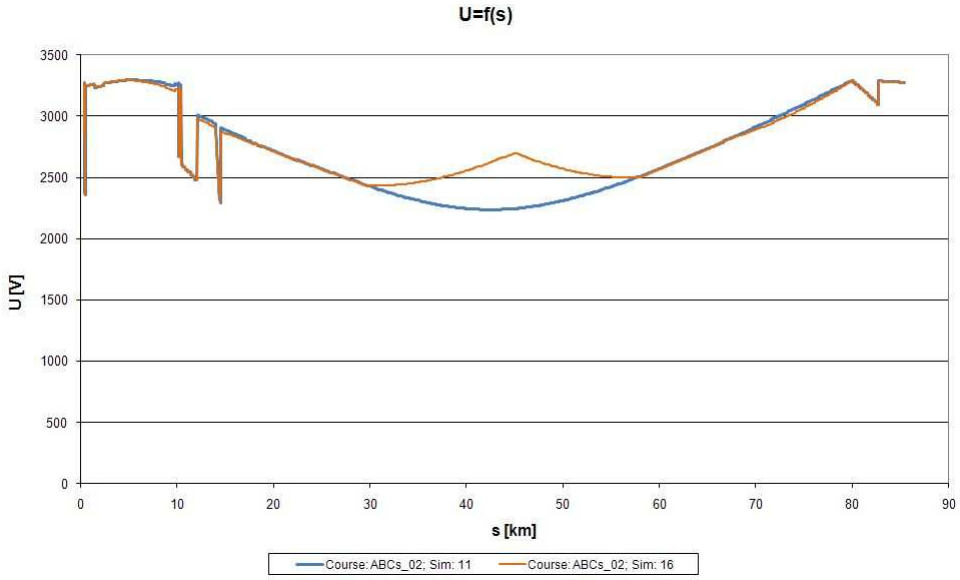


Figure 82 The line voltage at pantograph for course ABCs_02 in the DC network without (Sim 11) and with (Sim 16) energy storage type "Type_400A".

Using the prepared Excel file Storage2.xls we will compare the effect of the different maximum load and unload current of the energy storages. This file is available from menu `OpenPowerNet > Excel Tools > Compare Two Storages`.

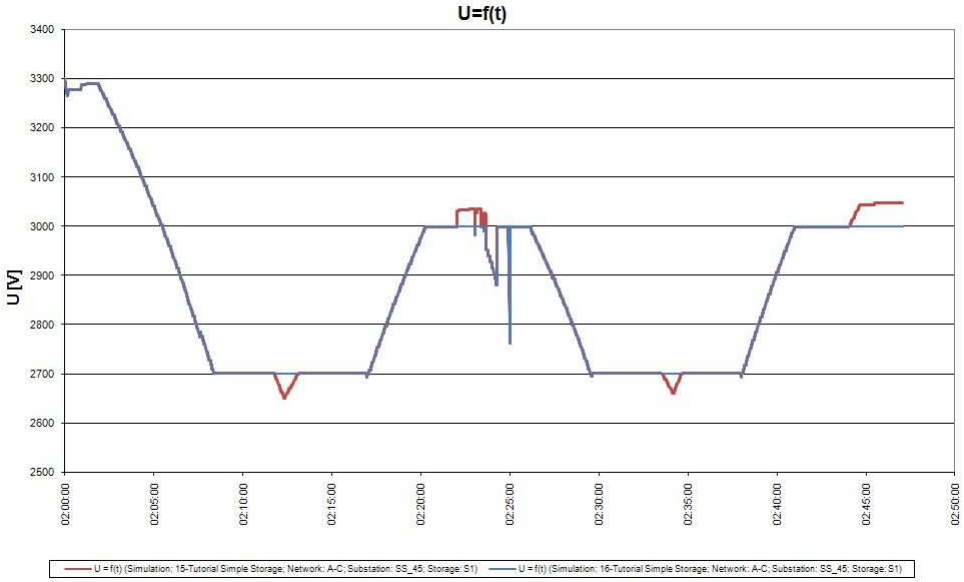


Figure 83 The line voltage at the substation with the storage for both storage types, "Type_400A" in simulation 16 and "Type_200A" in simulation 15.

For the energy storage type Type_200A we see that the voltage cannot be stabilised at 2700V because of the unload current limitation. The maximum load current limitation is visible at about 02:23 and 02:45.

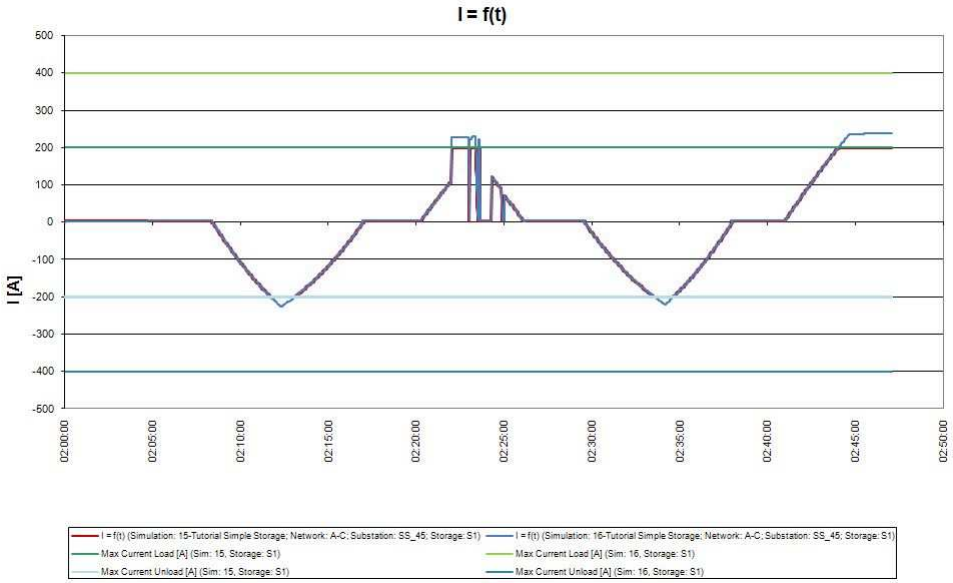


Figure 84 The load and unload current of both simulations, simulation 16 with 400A and simulation 15 with 200A load and unload current limitation.

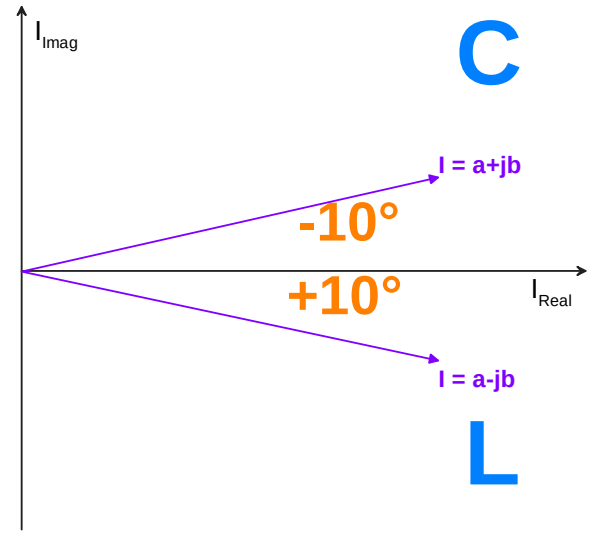
The diagram above clearly shows the different current limitations as well as the load and unload currents respecting their limitations.

6.6 Engine model

In the following tutorials we will configure different engine models and analyse the calculated simulation data. Each of following chapters describes one aspect of the engine model.

6.6.1 Power Factor tutorial

In the AC tutorial with failure scenario we experienced a significant voltage drop down to 24170 V for course CBAl_01. Now we will configure a capacitive behaviour of the engine in case of low voltage. Figure 85 describes the detailed behaviour and Figure 86 the values of the power factor for the engine model.



Legend:
The behaviour of the engine wether capacitive (C) or inductor (L).
The value of the power factor in the engine model.
The resulting current of the engine at the pantograph while driving.
For braking the currents are turned by 180°.

Figure 85 The engine power factor association between engine behaviour and model parameter.

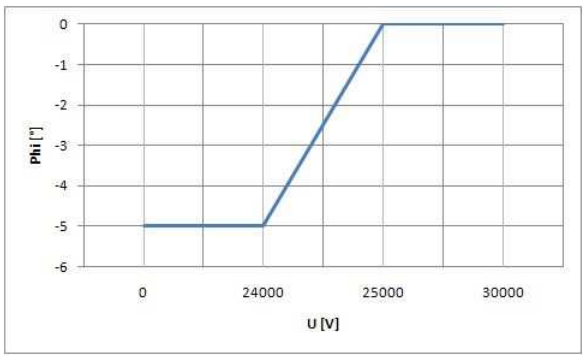


Figure 86 Power factor versus line voltage.

6.6.1.1 Configuration

6.6.1.1.1 OpenTrack

We will use the same OpenTrack data as for the AC tutorial described in chapter 6.2.1.1.

6.6.1.1.2 OpenPowerNet

6.6.1.1.2.1 Engine-File

As the basis for the Engine-File we use the one from the AC tutorial. As we want to have a power factor depending on the line voltage we need to specify the detailed curve, see the XML snipped below.

```
<fourQuadrantChopper typeStr="FQC 1">
  <phi>
    <valueTable xValueName="LineVoltage" xValueUnit="V" yValueName="Phi" yValueUnit="Deg">
      <valueLine xValue="0.0">     <values yValue="-5.0" /> </valueLine>
      <valueLine xValue="24000.0"> <values yValue="-5.0" /> </valueLine>
      <valueLine xValue="25000.0"> <values yValue="0.0" />  </valueLine>
    </valueTable>
  </phi>
</fourQuadrantChopper>
```

6.6.1.1.2.2 Project-File

We will amend the Project-File from AC tutorial in chapter 6.2.1.2.2. The four quadrant chopper model has to be defined in the Project-File, see XML snipped below.

```
<Vehicle eddyCurrentBrake="false" engineID="Engine1">
  <Propulsion
  engine="electric"
  supply="AC 25kV 50Hz"
  brakeCurrentLimitation="none"
  tractiveCurrentLimitation="none"
  useAuxPower="true"
  fourQuadrantChopperPhi="Phi=f(u)" This value need to be set to use the power factor
depending on line voltage.
  regenerativeBrake="none"
  tractiveEffort="maxPower/maxTractEffort">
  <MeanEfficiency />
  </Propulsion>
</Vehicle>
```

Furthermore we need to set the Switch-File same as for the failure scenario in the AC tutorial.

```
switchStateFile="D:\OPN_Projects\Tutorial\05_Engine_Model\01_Power_Factor\OPNData\Switch-
File.xml"
```

Set the right Engine-File and don't forget to set a meaningful project name and comment in the project file!

6.6.1.2 Simulation

We will run the simulation only with the long trains to see the effect of the power factor versus line voltage.

6.6.1.3 Analysis

We will use Engine2.xls and check to power factor of course CBAl_01 and compare the pantograph voltage with the failure simulation of the AC tutorial.

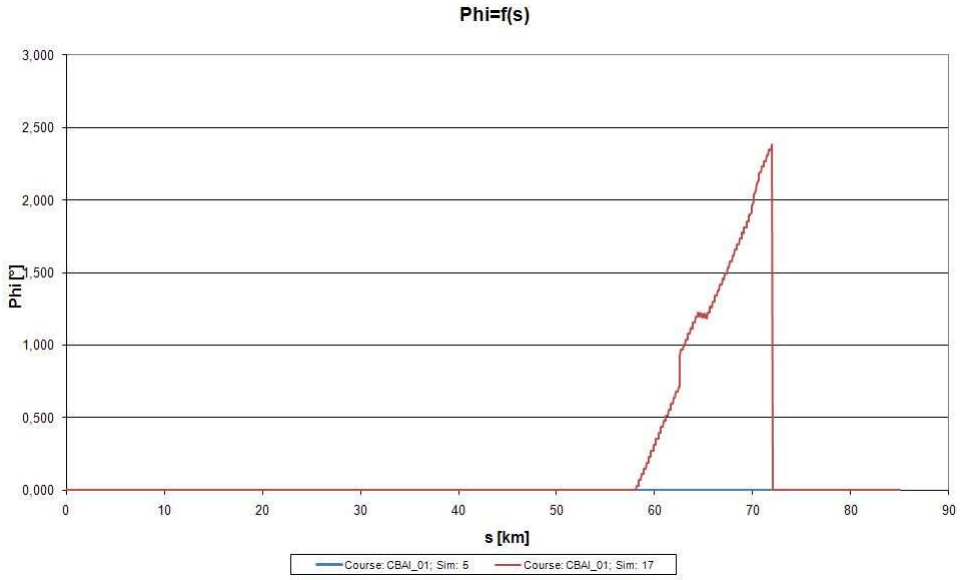


Figure 87 The pantograph current angle of course CBAI_01 versus location.

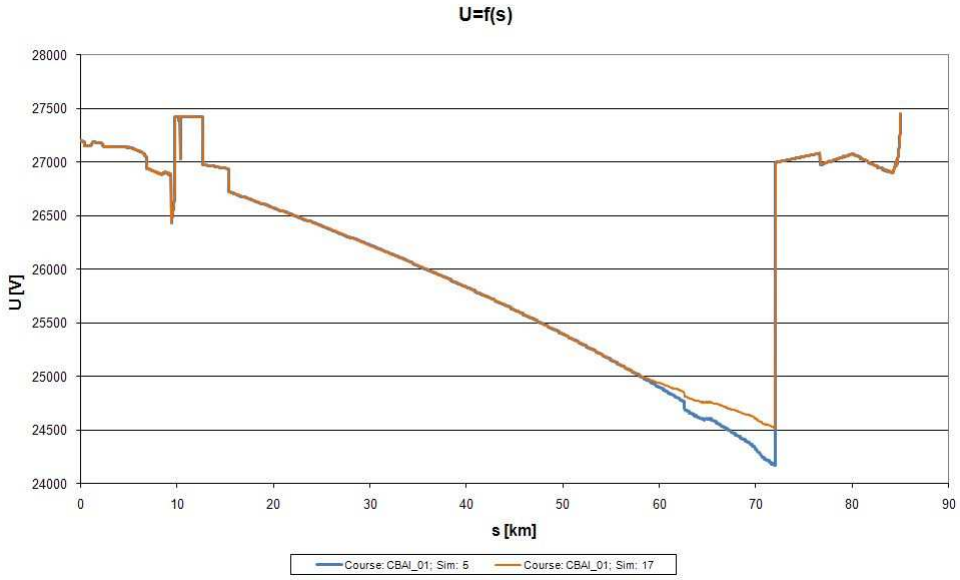


Figure 88 The pantograph position of course CBAI_01 with constant power factor of 0° (sim 5) and with power factor depending on line voltage (sim 17).

We can see very clear the line voltage supporting behaviour of the capacitive engine model used in this simulation.

6.6.2 Tractive effort tutorial

In this tutorial we want to use a table for the tractive effort characteristic of the engine. In the AC tutorial we used maximum power and maximum tractive effort to define the characteristic. The engine model is more flexible when using the table, see Figure 89.

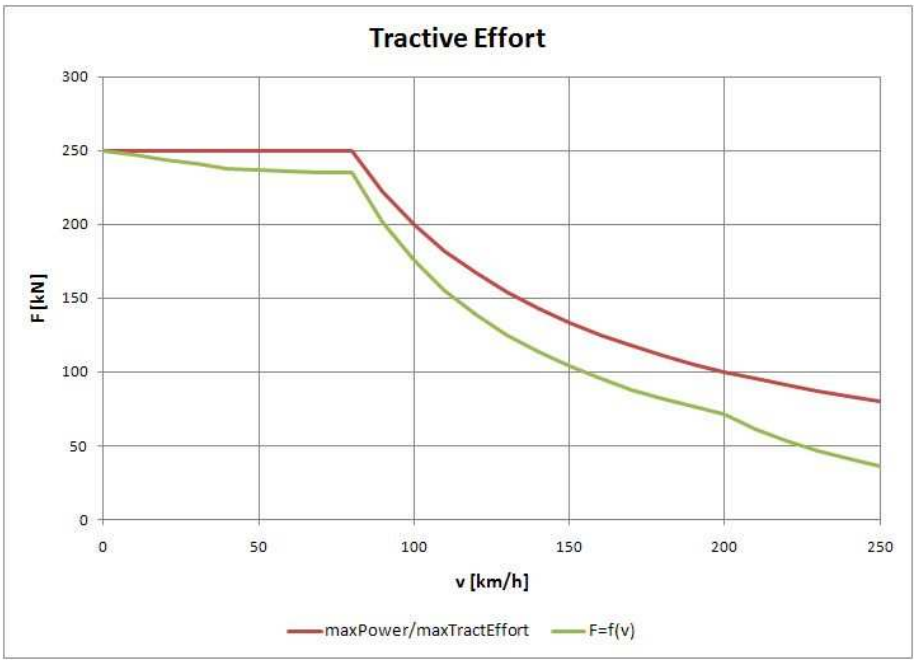


Figure 89 Possible characteristics of both available tractive effort models.

6.6.2.1 Configuration

6.6.2.1.1 OpenTrack

As the tractive effort characteristic curve in OpenTrack is always above the characteristic we defined in OpenPowerNet we don't need to change OpenTrack. The used tractive effort will be limited to the value defined in OpenPowerNet. Therefore we will use the same OpenTrack data as for the AC tutorial described in chapter 6.2.1.1.

6.6.2.1.2 OpenPowerNet

6.6.2.1.2.1 Engine-File

As the basis we take the Engine-File from the AC tutorial and add the tractive effort versus speed table. The XML snipped below has the detailed values.

```
<tractiveEffort>
  <valueTable xValueName="Speed" xValueUnit="km/h" yValueName="Tractive Effort"
yValueUnit="kN">
    <valueLine xValue="0">   <values yValue="250" /> </valueLine>
    <valueLine xValue="10">  <values yValue="247" /> </valueLine>
    <valueLine xValue="20">  <values yValue="244" /> </valueLine>
    <valueLine xValue="30">  <values yValue="241" /> </valueLine>
    <valueLine xValue="40">  <values yValue="238" /> </valueLine>
    <valueLine xValue="50">  <values yValue="237" /> </valueLine>
    <valueLine xValue="60">  <values yValue="236" /> </valueLine>
    <valueLine xValue="70">  <values yValue="235" /> </valueLine>
    <valueLine xValue="80">  <values yValue="235" /> </valueLine>
    <valueLine xValue="90">  <values yValue="202" /> </valueLine>
    <valueLine xValue="100"> <values yValue="176" /> </valueLine>
    <valueLine xValue="110"> <values yValue="155" /> </valueLine>
    <valueLine xValue="120"> <values yValue="139" /> </valueLine>
    <valueLine xValue="130"> <values yValue="125" /> </valueLine>
    <valueLine xValue="140"> <values yValue="114" /> </valueLine>
    <valueLine xValue="150"> <values yValue="104" /> </valueLine>
    <valueLine xValue="160"> <values yValue="95" />  </valueLine>
```

```
    <valueLine xValue="170"> <values yValue="88" />  </valueLine>
    <valueLine xValue="180"> <values yValue="82" />  </valueLine>
    <valueLine xValue="190"> <values yValue="76" />  </valueLine>
    <valueLine xValue="200"> <values yValue="71" />  </valueLine>
    <valueLine xValue="210"> <values yValue="61" />  </valueLine>
    <valueLine xValue="220"> <values yValue="53" />  </valueLine>
    <valueLine xValue="230"> <values yValue="47" />  </valueLine>
    <valueLine xValue="240"> <values yValue="41" />  </valueLine>
    <valueLine xValue="250"> <values yValue="36" />  </valueLine>
  </valueTable>
</tractiveEffort>
```

6.6.2.1.2.2 Project-File

```
<Vehicle eddyCurrentBrake="false" engineID="Engine1">
  <Propulsion
  engine="electric"
  supply="AC 25kV 50Hz"
  brakeCurrentLimitation="none"
  tractiveCurrentLimitation="none"
  useAuxPower="true"
  fourQuadrantChopperPhi="none"
  regenerativeBrake="none"
  tractiveEffort="F=f(v)"> This value need to be set to use the table model.
    <MeanEfficiency />
  </Propulsion>
</Vehicle>
```

Set the right Engine-File and don't forget to set a meaningful project name and comment in the project file!

6.6.2.2 Simulation

We need only to simulate the long trains to see effect of the changed tractive effort model of the engine.

6.6.2.3 Analysis

We use the Excel file Engine2.xls to compare course CBAl_01 of the AC network default simulation with this simulation.

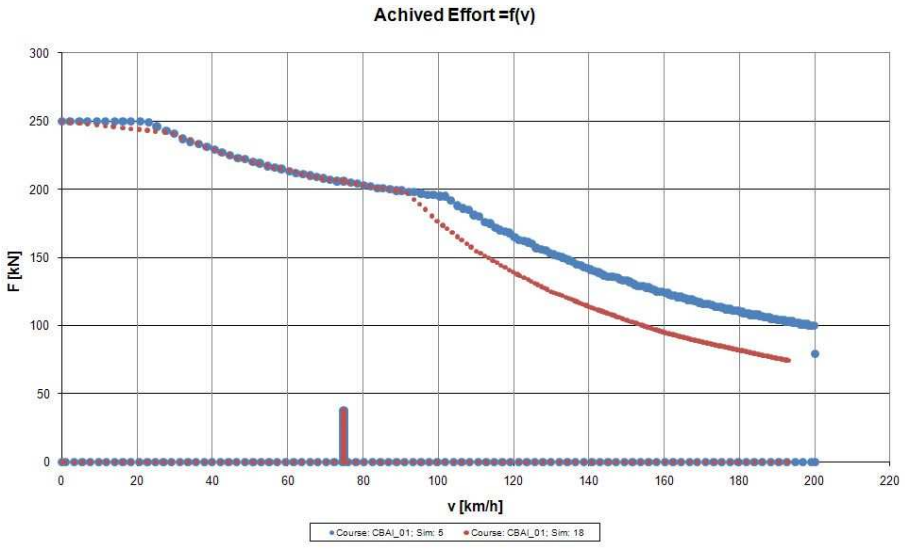


Figure 90 The tractive effort of course CBAl_01 from default AC network simulation (sim 5) and tractive effort table model simulation (sim 18).

When we compare the diagrams in Figure 90 and Figure 89 there seems to be a contradiction. The tractive effort between 25km/h and 100km/h is lower than expected.

This is because of the limited adhesion of the engine. By default the normal adhesion is used for the simulation in OpenTrack, see Figure 91. The adhesion type can be set using the Simulation panel of OpenTrack.

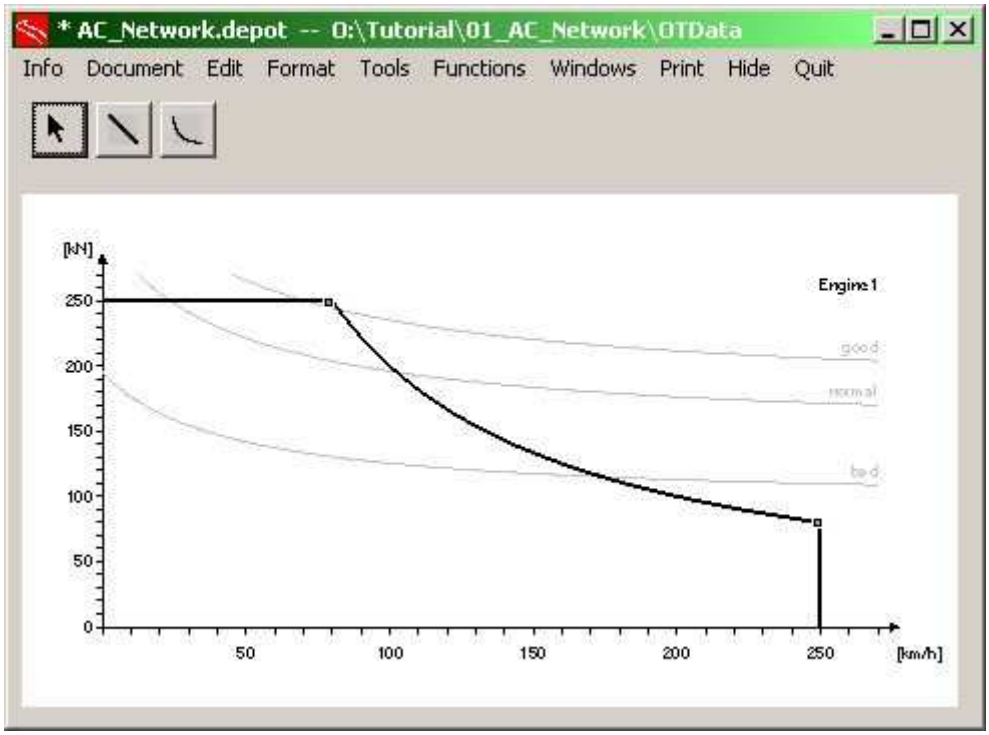


Figure 91 Tractive effort versus speed characteristic in OpenTarck engine model.

For the speed below 25km/h and above 100km/h we can see clearly the effect of the used table model compared with the maximum power / maximum effort model of the default AC network simulation.

6.6.3 Tractive current limitation tutorial

Please see the DC tutorial in chapter 6.4 for an example of tractive current limitation.

6.6.4 Regenerative braking tutorial

In this tutorial we will learn how to configure the OpenPowerNet engine model to use regenerative braking. The engine model shall be defined by maximum brake power and maximum brake effort. The values shall be the same as for traction.

6.6.4.1 Configuration

6.6.4.1.1 OpenTrack

We will use the OpenTrack model from the AC tutorial without changes.

6.6.4.1.2 OpenPowerNet

6.6.4.1.2.1 Engine-File

As the basis we use the Engine-File from the AC tutorial. We need only to set the values for max brake effort and max brake power, see the XML snipped below.

```
<vehicle length="25" bruttoWeight="75" vehicleID="Engine1" speed="250">
  <engine>
    <propulsion
    supply="AC 25kV 50Hz"
    transmission="electric"
    engine="electric"
    power="5560"
    maxTractEffort="250"
    totalTractEfficiency="90"
    totalBrakeEfficiency="90"
    maxBrakeEffort="250"  These and
    maxBrakePower="5560"> these values need to be set.
      <auxSupply typeStr="all" constPower="100" />
    </propulsion>
  </engine>
</vehicle>
```

6.6.4.1.2.2 Project-File

As the basis we use the Project-File from the AC tutorial. The regenerative effort model has to be specified. We want to use the `maxPower/maxEffort` model. A table same as for the tractive effort described in chapter 6.6.2 is also available.

```
<Vehicle eddyCurrentBrake="false" engineID="Engine1">
  <Propulsion
  engine="electric"
  supply="AC 25kV 50Hz"
  brakeCurrentLimitation="none"
  tractiveCurrentLimitation="none"
  useAuxPower="true"
  fourQuadrantChopperPhi="none"
  regenerativeBrake="maxPower/maxEffort" These property need to be set.
  tractiveEffort="maxPower/maxTractEffort">
    <MeanEfficiency />
  </Propulsion>
</Vehicle>
```

Set the right Engine-File and don't forget to set a meaningful project name and comment in the project file!

6.6.4.2 Simulation

We need only to simulate the long trains to see effect of the regenerative brake.

6.6.4.3 Analysis

The regenerative brake will only affect the simulation results during braking. In Figure 92 we can see the times of braking. In Figure 93 we can see very well the higher pantograph voltage from course ABCl_01 during the braking time of course ABCl_01 as well as course CBAl_01.

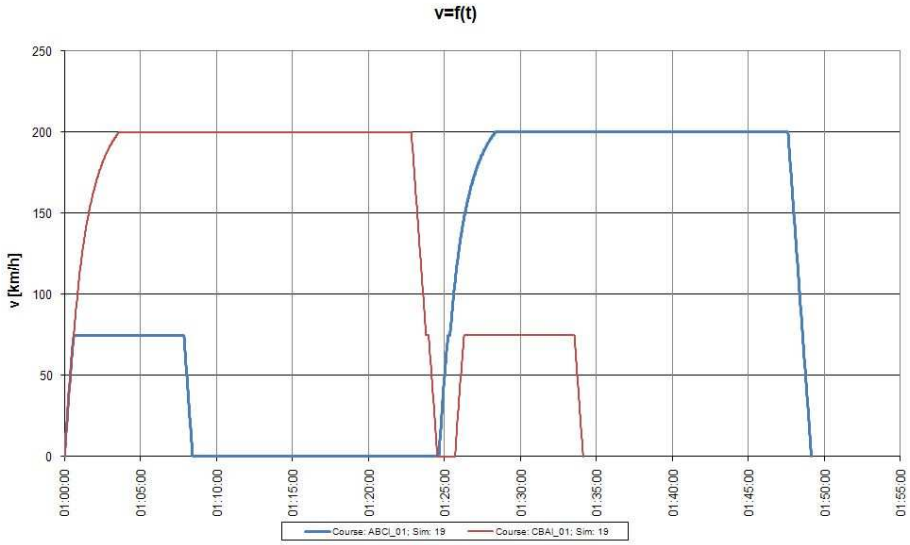


Figure 92 The speed versus time diagram of the courses in the regenerative brake simulation.

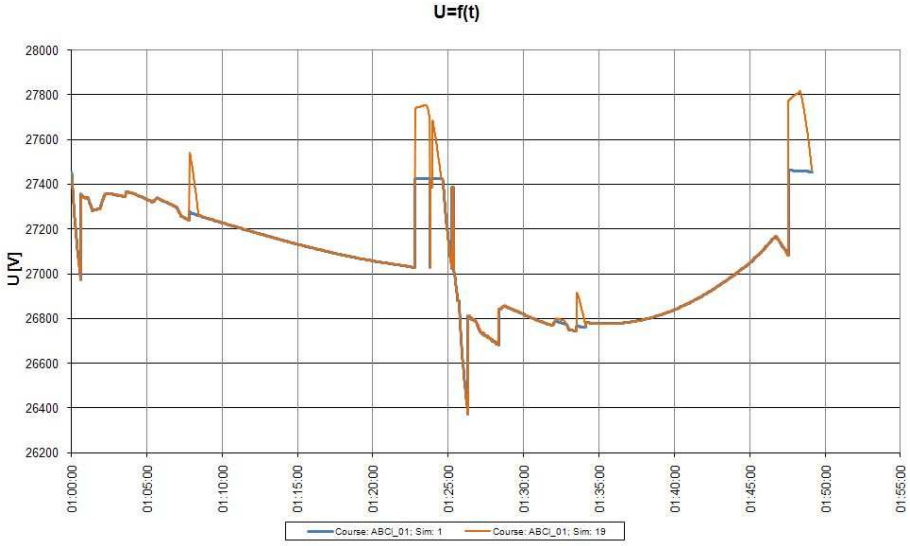


Figure 93 The pantograph voltage of course ABCl_01 for the AC network (sim 1) and the regenerative braking simulation (sim 19).

Figure 94 The current of both courses during the regenerative braking simulation

6.6.5 Brake current limitation tutorial

This tutorial describes the configuration of the brake current limitation and show the effect of the simulations results.

6.6.5.1 Configuration

6.6.5.1.1 OpenTrack

We will use the OpenTrack model from the AC tutorial without changes.

6.6.5.1.2 OpenPowerNet

6.6.5.1.2.1 Engine-File

We will take the Engine-File from the regenerative braking tutorial of chapter 6.6.4 as the basis. We need only to add the brake current limit to the engine propulsion, see the XML snipped below.

```
<propulsion ...
  <brakeCurrentLimitation>
    <valueTable xValueName="Line Voltage" xValueUnit="V" yValueName="Current" yValueUnit="A">
      <valueLine xValue="0.0"> <values yValue="50.0" /> </valueLine>
    </valueTable>
  </brakeCurrentLimitation>
</propulsion>
```

As the limit should be 50A for any line voltage we need only to specify the 50A at 0V.

6.6.5.1.2.2 Project-File

We will take the Project-File from the regenerative braking tutorial of chapter 6.6.4 as the basis. Only the `brakeCurrentLimitation` attribute need to be changed from `none` to `I=f(U)`, see the XML snuipped below.

```
<Vehicle eddyCurrentBrake="false" engineID="Engine1">
  <Propulsion
```

```
  engine="electric"
  supply="AC 25kV 50Hz"
  brakeCurrentLimitation="I=f(U)" These value need to be set.
  tractiveCurrentLimitation="none"
  useAuxPower="true"
  fourQuadrantChopperPhi="none"
  regenerativeBrake="maxPower/maxEffort"
  tractiveEffort="maxPower/maxTractEffort">
    <MeanEfficiency />
  </Propulsion>
</Vehicle>
```

Set the right Engine-File and don't forget to set a meaningful project name and comment in the project file!

6.6.5.2 Simulation

We need only to simulate the long trains to see effect of the brake current limitation.

6.6.5.3 Analysis

We use Excel file Engine2.xls to compare the simulation results from tutorial regenerative braking and this tutorial. Figure 95 shows the limited brake current to 50A.

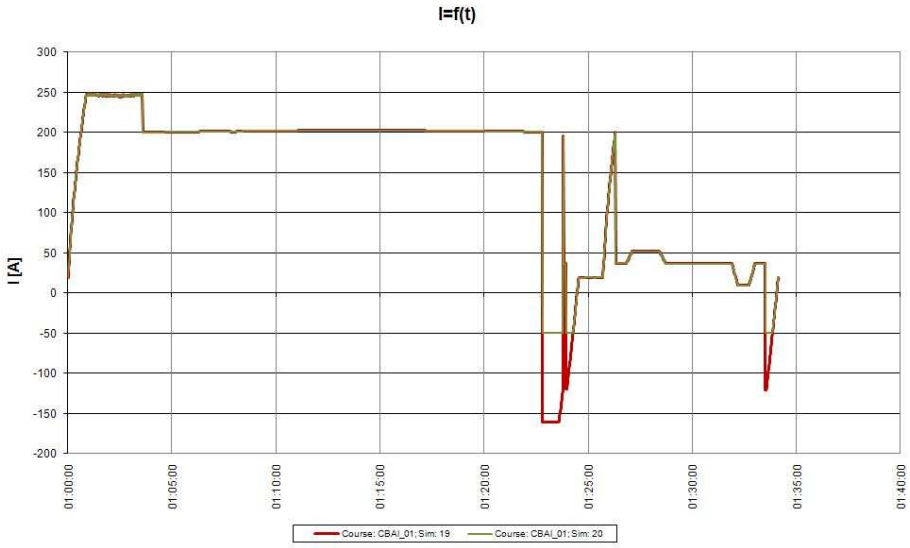


Figure 95 The current of course CBAI_01 without (sim 19) and with (sim 20) brake current limitation to 50A.

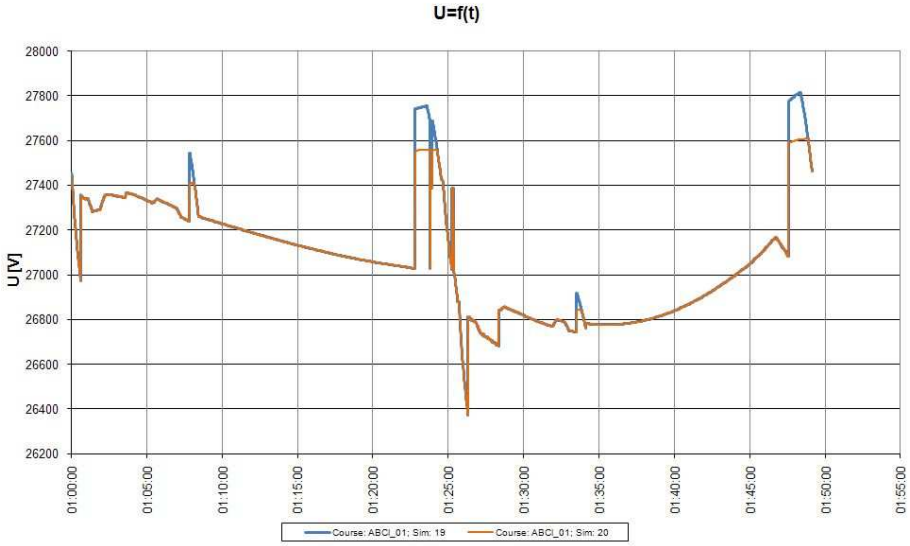


Figure 96 The pantograph voltage of course ABCl_01 witout (sim 19) and with (sim 20) brake current limitation.

The pantograph voltage of course ABCl_01 is lower during the time of regenerative braking because of the current limitation to 50A. Also the brake current limitation of course CBAl_01 during braking between 01:22:48 and 1:24:29, Figure 92, affect the pantograph voltage of the other course.

6.6.6 Auxiliary power tutorial

This tutorial describes the model of auxiliary power. The values of the auxiliary power are on one hand specified in OpenTrack and on the other in OpenPowerNet, see also the legend of Figure 5.

In OpenTrack the auxiliary power for each trailer of a train can be specified as a constant power. This is possible in the Train - Edit dialog of OpenTrack. In this tutorial we focus only on the possibilities in OpenPowerNet.

In OpenPowerNet we have 4 different auxiliary power models of an engine. It is possible to combine all 4 models within one engine. The auxiliary models are:

- Constant power,
- Constant resistance,
- Constant power during braking and
- Constant resistance during braking.

As the auxiliary power while braking is only active for regenerative engines we define the maximum regenerative brake power and maximum regenerative brake effort with the same values as for traction.

The value of the auxiliary power shall be 100 kW. The resistance shall produce a power of 100 kW at a pantograph voltage of 27.4 kV and is therefore 7507.4 Ω, see the formulas below.

$$R = \frac{U^2}{P}$$

$$7507.6\Omega = \frac{27400^2 V^2}{100000W}$$

To be able to compare the different auxiliary models we do 5 simulations. The first without auxiliary power and then one by one the different models.

As the short trains have less auxiliary power of the trailers we will use only the short trains to show clearly the effect of the engine auxiliary.

6.6.6.1 Configuration

6.6.6.1.1 OpenTrack

We will use the OpenTrack model from the AC tutorial without changes.

Select only the course ABCs_02 and CBAs_02 with short trains.

6.6.6.1.2 OpenPowerNet

We will use the Engine- and Project-File from the AC tutorial as the basis.

6.6.6.1.2.1 Engine-File

In the Engine-File we need to specify the maximum braking power and effort as well as the 4 different available auxiliary models. In the XML snipped below we see the constant auxiliary power and as comments the other three auxiliary power models. An XML comment is always between <!-- and -->.

```
<vehicle length="25" bruttoWeight="75" vehicleID="Engine1" speed="250">
  <engine>
    <propulsion
    supply="AC 25kV 50Hz"
    transmission="electric"
    engine="electric"
    power="5560"
    maxTractEffort="250"
    totalTractEfficiency="90"
    totalBrakeEfficiency="90"
    maxBrakePower="5560" We need to set the braking maximum power
    maxBrakeEffort="250"> and maximum brake effort.
      <auxSupply typeStr="constant power" constPower="100" />
      <!-- auxSupply typeStr="constant resistance" constResistance="7507.6" /-->
      <!-- auxSupply typeStr="constant power while braking" constPowerBraking="100" /-->
      <!-- auxSupply typeStr="constant resistance while braking"
constResistanceBraking="7507.6" /-->
/>
    </propulsion>
  </engine>
</vehicle>
```

For simulation 2 to 5 we use only one auxiliary power model and comment the others by using XML comment syntax.

6.6.6.1.2.2 Project-File

As we use short trains only and they start at 2:00 we have to set the simulation start time to 7200s.

```
simulationStart_s="7200"
```

Then we need to set the regenerative brake option and set the use of the engine auxiliary to false for the first simulation.

```
<Vehicle eddyCurrentBrake="false" engineID="Engine1">
  <Propulsion
  engine="electric"
  supply="AC 25kV 50Hz"
  brakeCurrentLimitation="none"
  tractiveCurrentLimitation="none"
  useAuxPower="false" Set this to false in the first simulation and to true for the other.
  fourQuadrantChopperPhi="none"
  regenerativeBrake="maxPower/maxEffort" Set this to use the regenerative brake.
  tractiveEffort="maxPower/maxTractEffort">
    <MeanEfficiency />
  </Propulsion>
</Vehicle>
```

Set the right Engine-File and don't forget to set a meaningful project name and comment in the project file!

6.6.6.2 Simulation

Run all simulation:

- Do everything as described above and run the simulation.
- Set `useAuxPower` in the Project-File to `true`, give a meaningful comment and run the simulation.
- Comment the auxiliary with **constant power** in the Engine-File and uncomment the **constant resistance** auxiliary, give a meaningful comment in the Project-File and run the simulation.
- Comment the auxiliary with **constant resistance** in the Engine-File and uncomment the **constant power while braking** auxiliary, give a meaningful comment in the Project-File and run the simulation.
- Comment the auxiliary with **constant power while braking** in the Engine-File and uncomment the **constant resistance while braking** auxiliary, give a meaningful comment in the Project-File and run the simulation.

6.6.6.3 Analysis

We use Excel file Engine2.xls to compare the simulations.

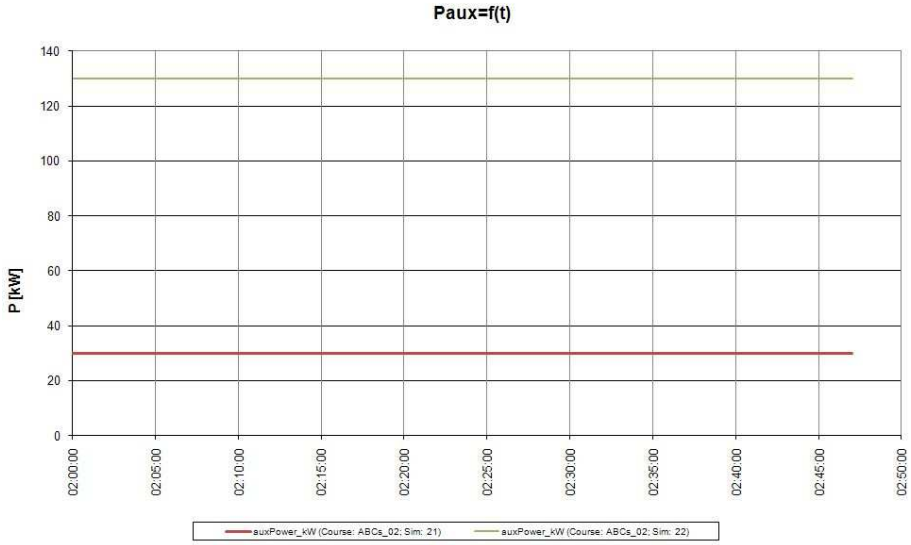


Figure 97 The auxiliary power of course ABCs_02 without engine auxiliary (sim 21) and with constant auxiliary power (sim 22).

In the diagram above we can see the auxiliary power of the trailers is 30kW and on top of this are the 100 kW of the engine. This is in total 130 kW for course ABCs_02.

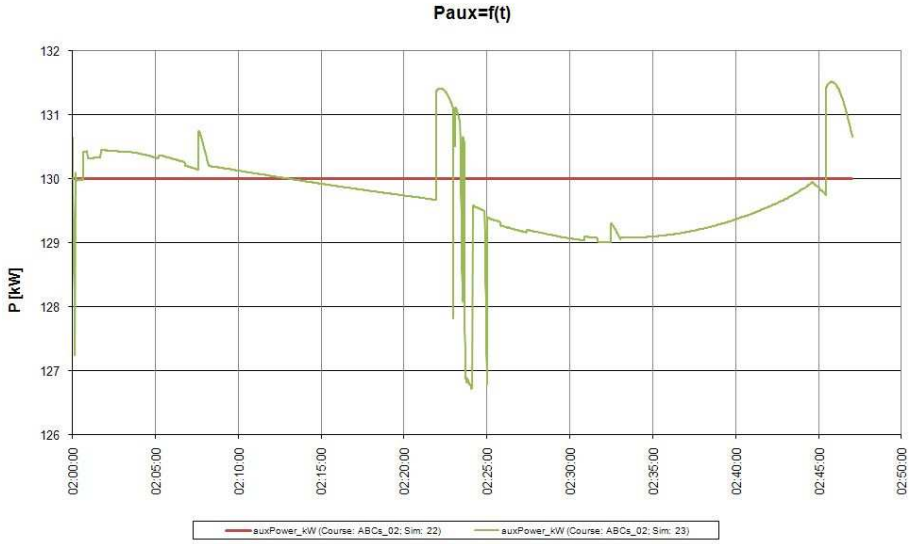


Figure 98 The auxiliary power of course ABCs_02 with constant engine auxiliary power (sim 22) and constant auxiliary resistance (23).

In Figure 98 we see the constant power and constant resistance auxiliary have about the same values. But of course the constant auxiliary has the auxiliary power as a function of the pantograph voltage, compare to the pantograph voltage in Figure 99.

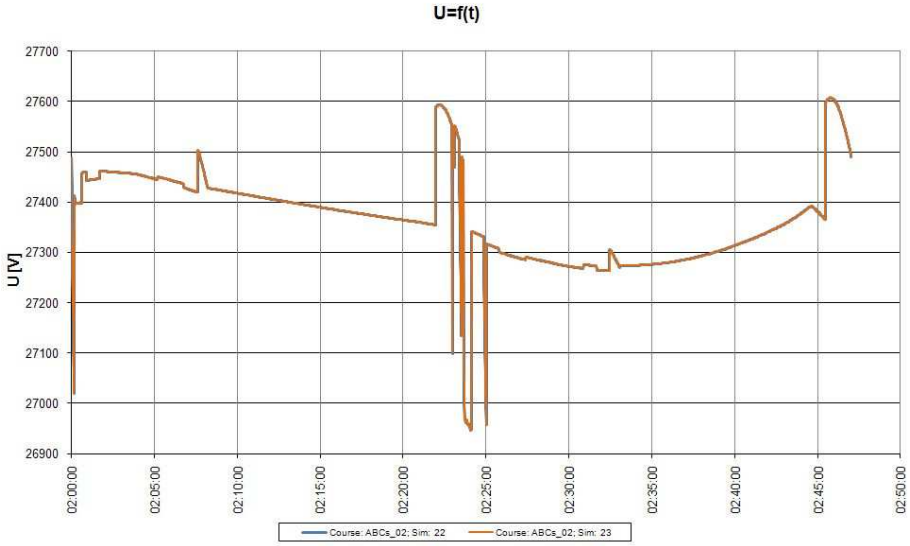


Figure 99 The pantograph voltage of course ABCs_02 with constant engine auxiliary power (sim 22) and constant auxiliary resistance (23).

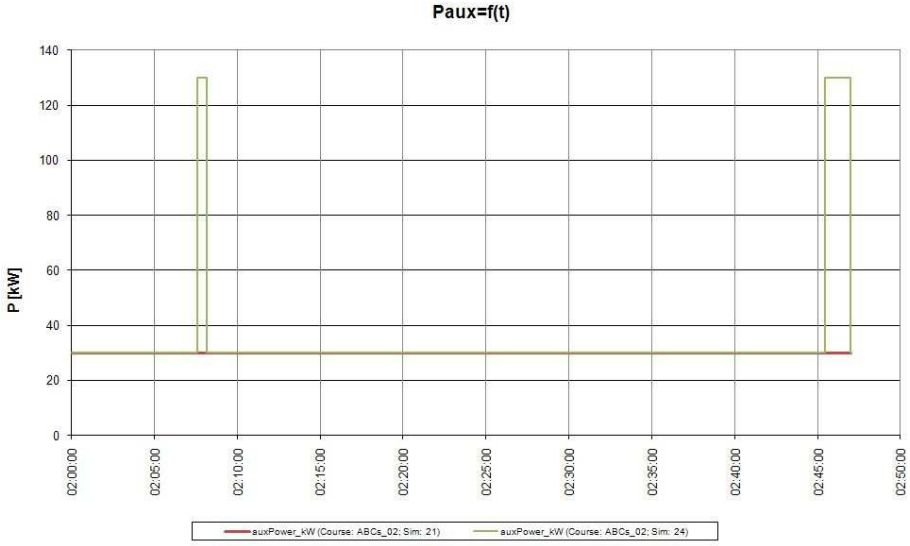


Figure 100 The auxiliary power of course ABCs_02 without engine auxiliary power (sim 21) and with constant auxiliary power while braking (sim 24).

In simulation 24 is the model with constant auxiliary power while braking used. We can identify the two time periods while braking and see the 100 kW additional to the 30 kW from the trailer auxiliary power.

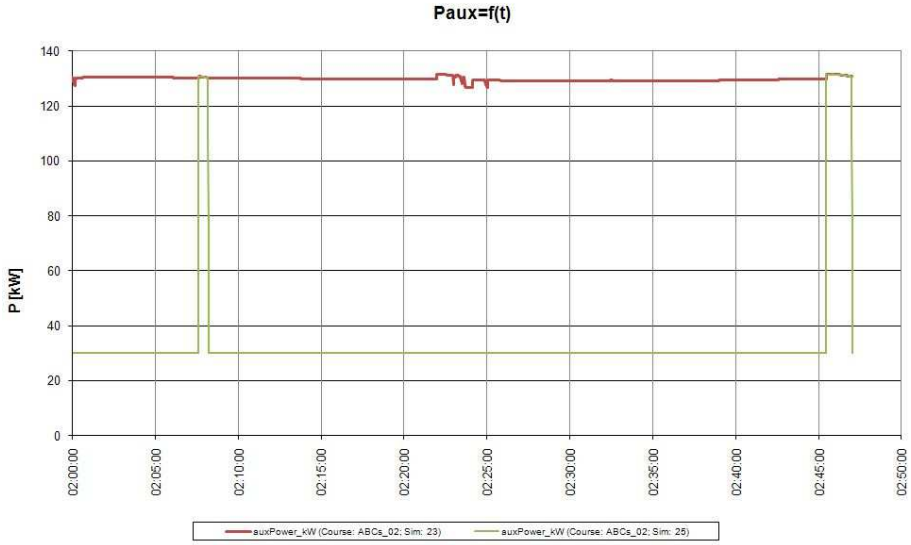


Figure 101 The auxiliary power of course ABCs_02 with constant engine auxiliary resistance (sim 23) and with constant auxiliary resistance while braking (sim 25).

In Figure 101 we see both resistance auxiliary models used for the simulations. During braking both curves are exactly the same but during driving they are different.

6.6.7 Eddy current brake tutorial

In this tutorial we use the eddy current brake.

As the eddy current braking is only active for regenerative engines we define

- the maximum regenerative brake power to 400 kW and
- maximum regenerative brake effort to 30 kN.

The parameter for the brake shall be

- 30 kN maximum effort,
- 300 kW maximum power and
- 10 km/h minimum speed.

As the short trains have less auxiliary power of the trailers we will use only the short trains to show clearly the effect of the eddy current brake.

To see the effect of the eddy current brake we do two simulations, one without and one with eddy current brake.

6.6.7.1 Configuration

6.6.7.1.1 OpenTrack

We will use the OpenTrack model from the AC tutorial without changes.

Select only the course ABCs_02 and CBAs_02 with short trains.

6.6.7.1.2 OpenPowerNet

We will use the Engine- and Project-File from the AC tutorial as the basis.

6.6.7.1.2.1 Engine-File

In the Engine-File we need to specify the maximum braking power and effort as well as the eddy current brake parameter.

```
<vehicle length="25" bruttoWeight="75" vehicleID="Engine1" speed="250">
  <engine>
    <propulsion
    supply="AC 25kV 50Hz"
    transmission="electric"
    engine="electric"
    power="5560"
    maxTractEffort="250"
    totalTractEfficiency="90"
    totalBrakeEfficiency="90"
    maxBrakePower="400" We need to set the braking maximum power
    maxBrakeEffort="30"> and maximum brake effort.
      <auxSupply typeStr="all" constPower="100" />
    </propulsion>
  </engine>
  <brakes>
    <eddyCurrentBrake This is the eddy current brake and there parameter.
    maxEffort="30"
    maxPower="300"
    minSpeed="10" />
  </brakes>
</vehicle>
```

6.6.7.1.2.2 Project-File

As we use short trains only and they start at 2:00 we have to set the simulation start time to 7200s.

```
simulationStart_s="7200"
```

Then we need to set the regenerative brake option and set the use of the eddy current brake to true for the second simulation.

```
<Vehicle
eddyCurrentBrake="false" This need to be set to false for the first and to true for the second
simulation.
engineID="Engine1">
  <Propulsion
  engine="electric"
  supply="AC 25kV 50Hz"
  brakeCurrentLimitation="none"
  tractiveCurrentLimitation="none"
  useAuxPower="true"
  fourQuadrantChopperPhi="none"
  regenerativeBrake="maxPower/maxEffort" Set this to use the regenerative brake.
  tractiveEffort="maxPower/maxTractEffort">
    <MeanEfficiency />
  </Propulsion>
</Vehicle>
```

Set the right Engine-File and don't forget to set a meaningful project name and comment in the project file!

6.6.7.2 Simulation

Run both simulations:

- Do everything as described above and run the simulation.
- Change the attribute `eddyCurrentBrake` in the Project-File to `true`, give a meaningful comment in the Project-File and run the simulation.

6.6.7.3 Analysis

We use Excel file Engine2.xls to compare the simulation. As we are only interested in the values while braking we filter the column with requested effort and select only the values < 0. This has to be done for both SELECTION sheets.

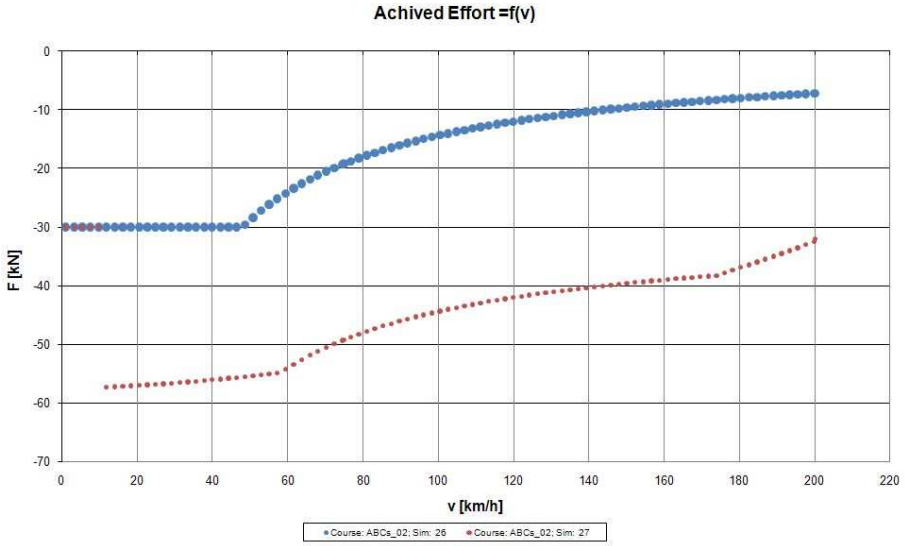


Figure 102 The achived effort by the engine of course ABCs_02 without (sim 26) and with (sim 27) eddy current brake.

Between 60 km/h and 170 km/h the achived brake effort of the simulation with eddy current brake (sim 27) is 30 kN more than without. Note that for a speed less than 10 km/h both curves are the same.

For the other speeds the achived effort in simulation 27 is just as much as requested, compare also the values in sheet SELECTION (2).

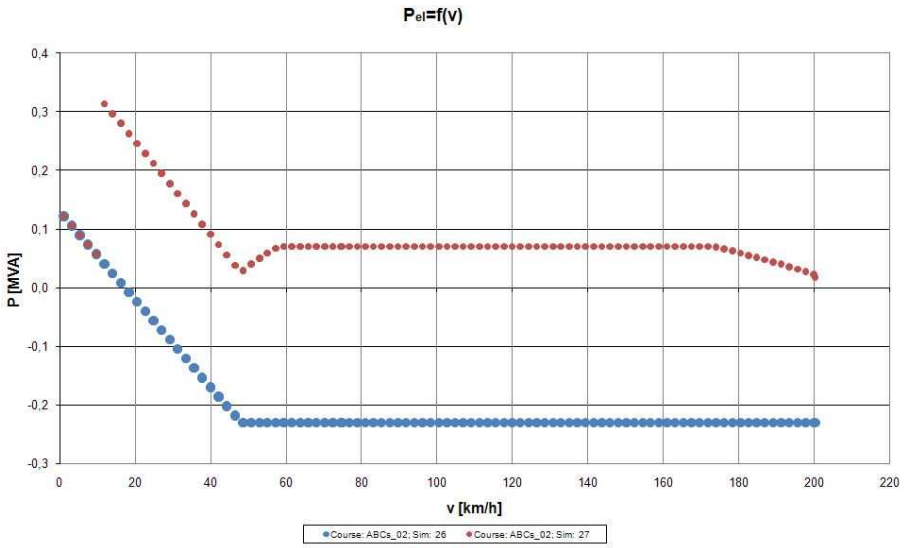


Figure 103 The electrical power by course ABCs_02 without (sim 26) and with (sim 27) eddy current brake.

Because of the eddy current brake we see the behaviour of the course ABCs_02 changed from regenerative to consuming. Between 60 km/h and 170 km/h the difference is the maximum power of the eddy current brake of 300 kW

6.6.8 Mean efficiency model tutorial

The mean efficiency model is used for all previous tutorials. Read the AC tutorial in chapter 6.2 für details.

6.6.9 Efficiency table model tutorial

In this tutorial we use the efficiency table model of the engine to describe the efficiency versus speed.

The engine shall an engine with recovery braking and the efficiencies for driving and braking shall be the same.

6.6.9.1 Configuration

6.6.9.1.1 OpenTrack

We will use the OpenTrack model from the AC tutorial without changes.

Select only the course ABCl_01 and CBAl_01 with short trains.

6.6.9.1.2 OpenPowerNet

We will use the Engine- and Project-File from the AC tutorial as the basis.

6.6.9.1.2.1 Engine-File

We need to add to the Engine-File the values for recovery braking and the efficiency values for traction and braking.

```
<vehicle length="25" bruttoWeight="75" vehicleID="Engine1" speed="250">
  <engine>
    <propulsion
    supply="AC 25kV 50Hz"
    transmission="electric"
    engine="electric"
    power="5560"
    maxTractEffort="250"
    totalTractEfficiency="90" This values will be ignored if we choose
    totalBrakeEfficiency="90" efficiency table model in the Project-File.
    maxBrakePower="5560"
    maxBrakeEffort="250">
      <auxSupply typeStr="all" constPower="100" />
      <tractiveVehicleEfficiency> The efficiency for traction.
        <valueTable xValueName="Speed" xValueUnit="km/h" yValueName="Efficiency"
yValueUnit="%">
          <valueLine xValue="0">   <values yValue="40" /> </valueLine>
          <valueLine xValue="10">  <values yValue="75" /> </valueLine>
          <valueLine xValue="30">  <values yValue="85" /> </valueLine>
          <valueLine xValue="50">  <values yValue="88" /> </valueLine>
          <valueLine xValue="80">  <values yValue="91" /> </valueLine>
          <valueLine xValue="150"> <values yValue="91" /> </valueLine>
          <valueLine xValue="250"> <values yValue="88" /> </valueLine>
        </valueTable>
      </tractiveVehicleEfficiency>
      <brakeVehicleEfficiency> The efficiency for braking.
```

```
        <valueTable xValueName="Speed" xValueUnit="km/h" yValueName="Efficiency"
yValueUnit="%">
          <valueLine xValue="0">   <values yValue="40" /> </valueLine>
          <valueLine xValue="10">  <values yValue="75" /> </valueLine>
          <valueLine xValue="30">  <values yValue="85" /> </valueLine>
          <valueLine xValue="50">  <values yValue="88" /> </valueLine>
          <valueLine xValue="80">  <values yValue="91" /> </valueLine>
          <valueLine xValue="150"> <values yValue="91" /> </valueLine>
          <valueLine xValue="250"> <values yValue="88" /> </valueLine>
        </valueTable>
      </brakeVehicleEfficiency>
    </propulsion>
  </engine>
</vehicle>
```

6.6.9.1.2.2 Project-File

In the Project-File we need to set only the regenerative brake and to specify the efficiency model.

```
<Vehicle eddyCurrentBrake="false" engineID="Engine1">
  <Propulsion
  engine="electric"
  supply="AC 25kV 50Hz"
  brakeCurrentLimitation="none"
  tractiveCurrentLimitation="none"
  useAuxPower="true"
  fourQuadrantChopperPhi="none"
  regenerativeBrake="maxPower/maxEffort" Set this to use regenerative braking.
  tractiveEffort="maxPower/maxTractEffort">
    <MeanEfficiency />Use this element to specify the efficiency model in the second
simulation by replacing this element with <EfficiencyTable />.
  </Propulsion>
</Vehicle>
```

Set the right Engine-File and don't forget to set a meaningful project name and comment in the project file!

6.6.9.2 Simulation

We will do two simulations to be able to compare the mean efficiency with the table efficiency model.

Run both simulations:

- Do everything as described above and run the simulation.
- Replace `<MeanEfficiency />` with `<EfficiencyTable />`, give a meaningful comment in the Project-File and run the simulation.

6.6.9.3 Analysis

We use Excel file Engine2.xls to compare the simulation.

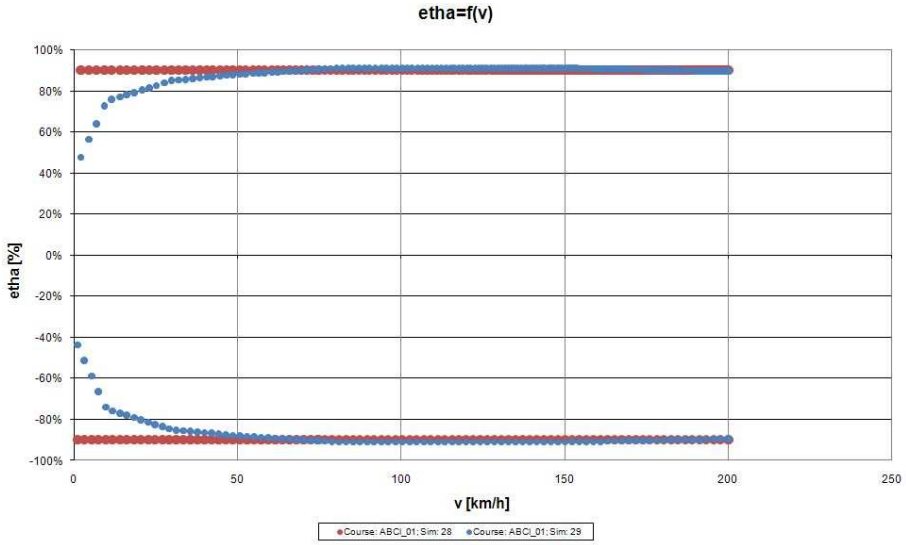


Figure 104 The efficiencies of course ABCI_01 with mean efficiency and efficiency table model.

6.6.10 Single component model

This tutorial describes the handling of the single component model of the engine, see also Figure 3. The components of the model are:

- Transformer,
- Four quadrant chopper,
- Traction inverter,
- Motor and
- Gear.

The efficiencies shall be as in Figure 105. Note that the transformer efficiency is versus current and the others constant or versus speed. To see the effect of the transformer efficiency we will run one simulation with an mean transformer efficiency of 98 % and one simulation with the efficiency as in Figure 105.

We will use the courses with longs trains.

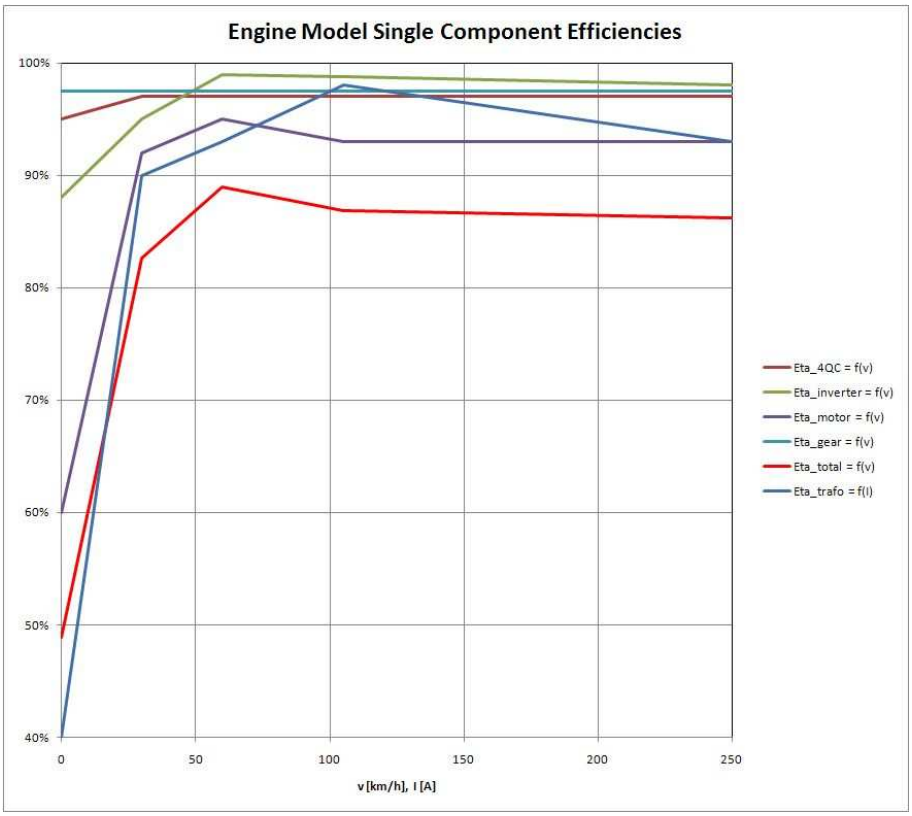


Figure 105 The efficiencies of the engine components.

6.6.10.1 Configuration

6.6.10.1.1 OpenTrack

We will use the OpenTrack model from the AC tutorial without changes.

Select only the course ABCI_01 and CBAI_01 with long trains.

6.6.10.1.2 OpenPowerNet

We will use the Engine- and Project-File from the AC tutorial as the basis.

6.6.10.1.2.1 Engine-File

In the Engine-File we need to define all the efficiencies of the engine model.

```
<vehicle length="25" bruttoWeight="75" vehicleID="Engine1" speed="250">
  <engine>
    <propulsion
    supply="AC 25kV 50Hz"
    transmission="electric"
    engine="electric"
    power="5560"
    maxTractEffort="250"
    totalTractEfficiency="90"
    totalBrakeEfficiency="90">
      <transformer typeStr="" meanEfficiency="98" count="1">
        <efficiency>
```

```
          <valueTable
          xValueName="Current"
          xValueUnit="A" The current and
          yValueName="Efficiency"
          yValueUnit="1"> the efficiency unit.
            <valueLine xValue="0">   <values yValue="0.4" />  </valueLine>
            <valueLine xValue="30">  <values yValue="0.9" />  </valueLine>
            <valueLine xValue="60">  <values yValue="0.93" /> </valueLine>
            <valueLine xValue="105"> <values yValue="0.98" /> </valueLine>
            <valueLine xValue="250"> <values yValue="0.93" /> </valueLine>
          </valueTable>
        </efficiency>
      </transformer>
      <fourQuadrantChopper typeStr="">
        <efficiency>
          <valueTable
          xValueName="Speed"
          xValueUnit="km/h" The speed and
          yValueName="Efficiency"
          yValueUnit="1"> the efficiency unit.
            <valueLine xValue="0">   <values yValue="0.95" /> </valueLine>
            <valueLine xValue="30">  <values yValue="0.97" /> </valueLine>
          </valueTable>
        </efficiency>
      </fourQuadrantChopper>
      <tractionInverter typeStr="">
        <efficiency>
          <valueTable
          xValueName="Speed"
          xValueUnit="km/h" The speed and
          yValueName="Efficiency"
          yValueUnit="1"> the efficiency unit.
            <valueLine xValue="0">   <values yValue="0.88" /> </valueLine>
            <valueLine xValue="30">  <values yValue="0.95" /> </valueLine>
            <valueLine xValue="60">  <values yValue="0.99" /> </valueLine>
            <valueLine xValue="250"> <values yValue="0.98" /> </valueLine>
          </valueTable>
        </efficiency>
      </tractionInverter>
      <tractionMotor typeStr="">
        <efficiency>
          <valueTable
          xValueName="Speed"
          xValueUnit="km/h" The speed,
          yValueName="Efficiency"
          yValueUnit="1"> the efficiency and
          zValueName="Effort"
          zValueUnit="kN"> the effort unit.
We want to use the same efficiency for any traction force therefore the values between 0 kN
and 250 kN are the same.
                              the column for 0 kN                and for 250 kN
                        <columnHeader zValue="0" /> <columnHeader zValue="250" />
            <valueLine xValue="0">  <values yValue="0.6"/> <values yValue="0.6"/> </valueLine>
            <valueLine xValue="30"> <values yValue="0.92"/><values yValue="0.92"/></valueLine>
            <valueLine xValue="60"> <values yValue="0.95"/><values yValue="0.95"/></valueLine>
            <valueLine xValue="105"><values yValue="0.93"/><values yValue="0.93"/></valueLine>
            <valueLine xValue="250"><values yValue="0.93"/><values yValue="0.93"/></valueLine>
          </valueTable>
        </efficiency>
      </tractionMotor>
      <gear typeStr="" ratio="1" meanEfficiency="97.5">
      </gear>
      <auxSupply typeStr="all" constPower="100" />
    </propulsion>
  </engine>
</vehicle>
```

6.6.10.1.2.2 Project-File

In the Project file we need to change the efficiency model to Single component.

```
<Vehicle eddyCurrentBrake="false" engineID="Engine1">
  <Propulsion
  engine="electric"
  supply="AC 25kV 50Hz"
  brakeCurrentLimitation="none"
  tractiveCurrentLimitation="none"
  useAuxPower="true"
  fourQuadrantChopperPhi="none"
  regenerativeBrake="none"
  tractiveEffort="maxPower/maxTractEffort">
    <SingleComponent This element specifies the efficiency model.
    transformer="meanEfficiency" The efficiencies are mean,
    fourQuadrantChopperEfficiency="efficiency=f(v)" versus speed,
    tractionInverter="efficiency=f(v)" versus speed,
    gear="meanEfficiency" mean and
    tractionMotor="efficiency=f(v, F)" /> versus speed and force.
  </Propulsion>
</Vehicle>
```

Set the right Engine-File and don't forget to set a meaningful project name and comment in the project file!

6.6.10.2 Simulation

We will do two simulations to be able to compare two transformer efficiency models.

Run both simulations:

- Do everything as described above and run the simulation.
- Change the attribute `transformer` in the Project-File to `efficiency=f(I)`, give a meaningful comment in the Project-File and run the simulation.

6.6.10.3 Analysis

We use Excel file Engine2.xls to compare the simulation. We have to set the transformer efficiency in the SELECTION sheet to display the correct curves.

Figure 106 The cell in the Excel sheet SELECTION to set the transformer efficiency.

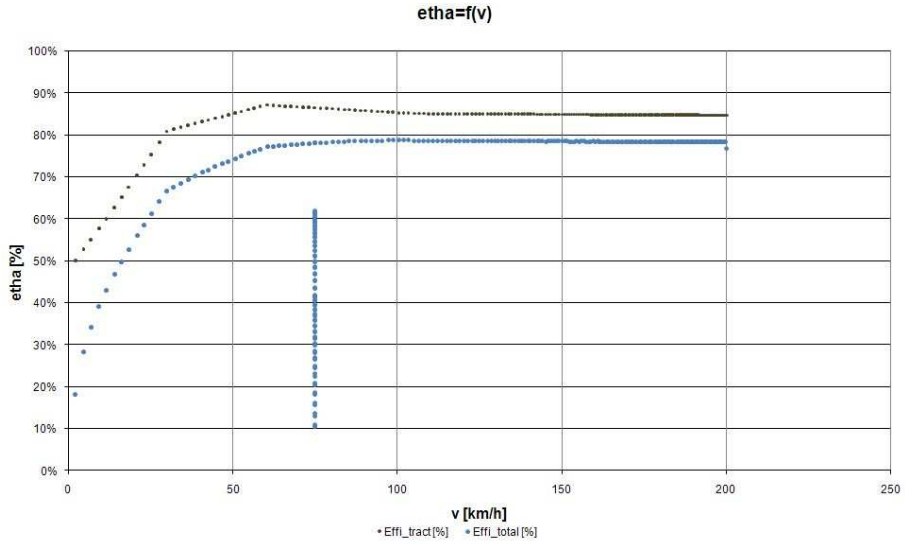


Figure 107 The tractive and total efficiency of course ABCl_01 versus speed.

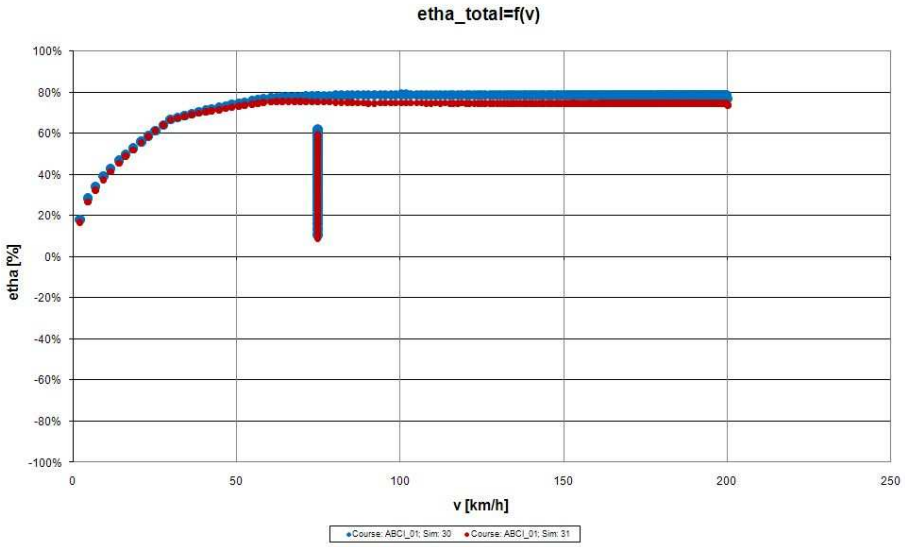


Figure 108 The total efficiency of course ABCl_01 with mean (sim 30) and versus current (sim 31) transformer efficiency.

6.7 Network model

In the following tutorials we will focus on advanced network configuration.

6.7.1 Substations tutorial

In this tutorial we will create a substation two transformers. Each transformer shall have a busbar and connectors between them. The substation shall be same as in Figure 109 but with two winding transformers. The infeeds shall be at km 5+000 and km 6+000.

At 1:04:30 one transformer shall be disconnected and at 1:05:00 the other shall feed the left and the right section.

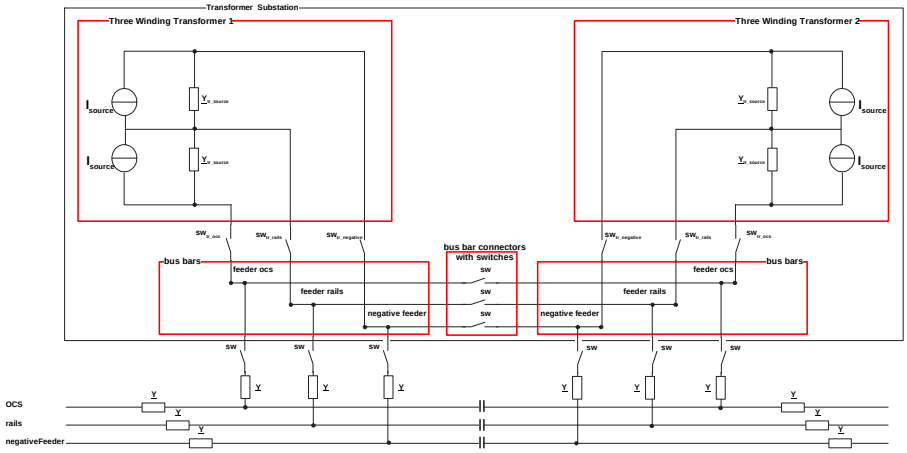


Figure 109 A substation with two transformers, busbars and busbar connection.

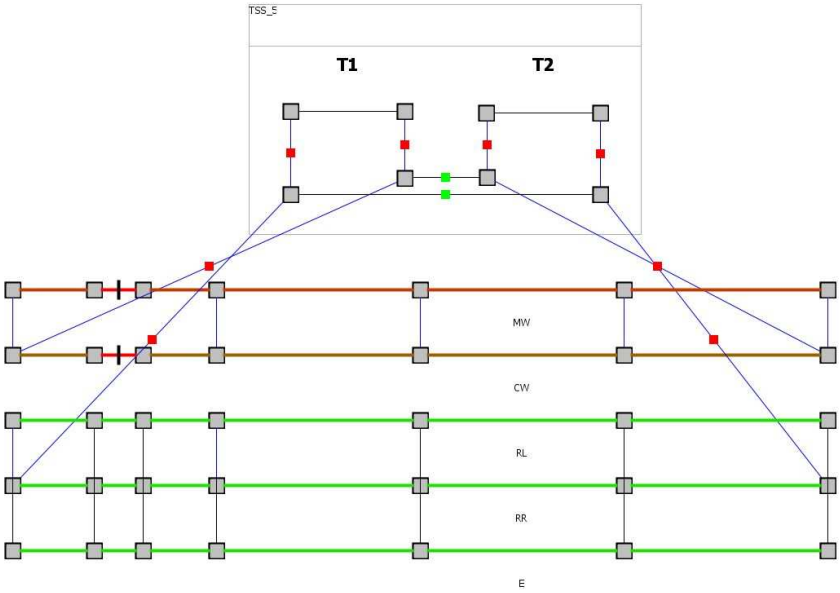


Figure 110 The wrong configuration of the feeder from substation to the line.

The sum of the conductor current will not be zero because connectors are parallel to conductors and allow the current to bypass the conductor. See the constraints listed in chapter 4.2.1.

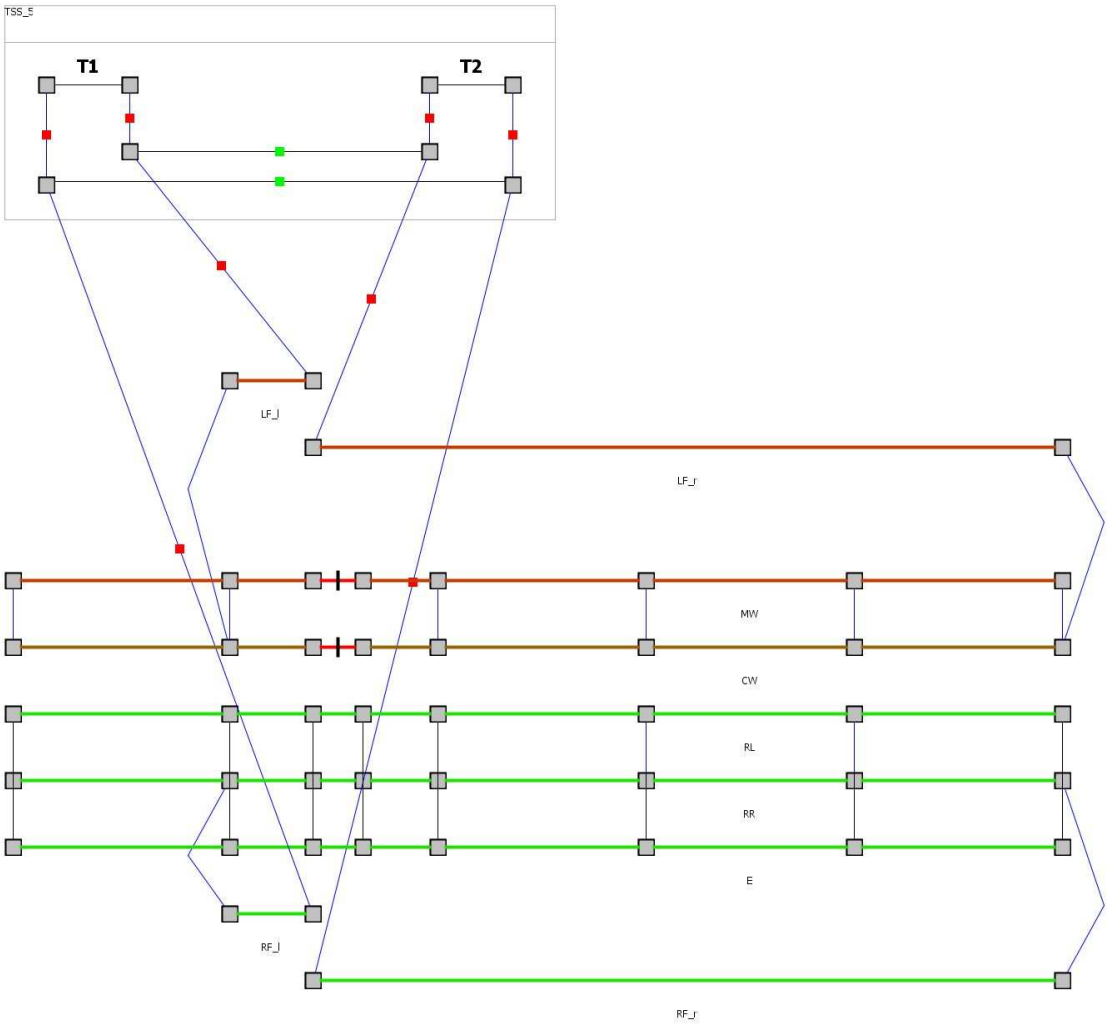


Figure 111 The correct configuration of the substation with all infeeds at the same slice.

To see the effect of the wrong and the correct configuration we run both simulations and record all currents and voltages between km 0+000 and km 9+000.

6.7.1.1 Configuration

6.7.1.1.1 OpenTrack

We will use the OpenTrack model from the AC tutorial without changes.

Select only the course ABCl_01 and CBAl_01 with long trains.

6.7.1.1.2 OpenPowerNet

We will use the Engine- and Project-File from the AC tutorial as the basis.

6.7.1.1.2.1 Engine-File

For this tutorial we don't need to change the Engine-File.

6.7.1.1.2.2 Project-File

As there are two different configurations we will have two Project-Files. One Project-File with the wrong configuration same as in Figure 110 and one Project-File with the correct configuration same as in Figure 111.

First we do the Project-File with the wrong configuration. The substation TSS_5 shall be adapted and the network shall be split at km 5+100 by adding isolators in the messenger and contact wire.

First we add the isolators to the line. The XML snipped below if nested in the element `Line`.

```
<Isolators>
  <ConductorIsolator>
    <Position km="5.1" trackID="1" condName="CW" />
  </ConductorIsolator>
  <ConductorIsolator>
    <Position km="5.1" trackID="1" condName="MW" />
  </ConductorIsolator>
</Isolators>
```

Next is to add the second transformer to TSS_5 and to add the infeeds.

```
<Substation name="TSS_5">
  <TwoWindingTransformer name="T1" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="27.5" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
    <OCSBB
    bbName="OCS_BB_1" The new busbar name.
    z_real_Ohm="0.001"
    z_imag_Ohm="0">
      <Switch name="TSS_5_T1_OCS" defaultState="close" />
    </OCSBB>
    <RailsBB
    bbName="Rails_BB_1" The new busbar name.
    z_real_Ohm="0.001"
    z_imag_Ohm="0">
      <Switch name="TSS_5_T1_Rails" defaultState="close" />
    </RailsBB>
  </TwoWindingTransformer> This is the second transformer with the same properties as T1.
  <TwoWindingTransformer name="T2" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="27.5" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
    <OCSBB bbName="OCS_BB_2" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="TSS_5_T2_OCS" defaultState="close" />
    </OCSBB>
    <RailsBB bbName="Rails_BB_2" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="TSS_5_T2_Rails" defaultState="close" />
    </RailsBB>
  </TwoWindingTransformer>
  <Busbars>
    <OCSBB bbName="OCS_BB_1"> Change the name to make a unique busbar name.
      <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="CW" lineID="A" trackID="1" km="5" />
        <Switch defaultState="close" name="TSS_5_OCS_Feeder_5.0" />
      </Connector>
    </OCSBB>
    <RailsBB bbName="Rails_BB_1"> Change the name to make a unique busbar name.
      <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="RR" lineID="A" trackID="1" km="5" />
        <Switch defaultState="close" name="TSS_5_Rails_Feeder_5.0" />
      </Connector>
    </RailsBB>
    <OCSBB bbName="OCS_BB_2">
      <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="CW" lineID="A" trackID="1" km="6" />
        <Switch defaultState="close" name="TSS_5_OCS_Feeder_6.0" ></Switch>
      </Connector>
    </OCSBB>
    <RailsBB bbName="Rails_BB_2">
```

```
      <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="RR" lineID="A" trackID="1" km="6" />
        <Switch defaultState="close" name="TSS_5_Rails_Feeder_6.0" />
      </Connector>
    </RailsBB>
  </Busbars>
Here the busbar connectors including switches:
  <OCSBBConnector z_imag_Ohm="0.0" z_real_Ohm="0.001">
    <BusbarFrom bbName="OCS_BB_1" />
    <BusbarTo bbName="OCS_BB_2" />
    <Switch defaultState="open" name="TSS_5_OCS_BB" />
  </OCSBBConnector>
  <RailsBBConnector z_imag_Ohm="0.0" z_real_Ohm="0.001">
    <BusbarFrom bbName="Rails_BB_1" />
    <BusbarTo bbName="Rails_BB_2" />
    <Switch defaultState="open" name="TSS_5_Rails_BB" />
  </RailsBBConnector>
</Substation>
```

To minimise the recorded data we will record voltages and currents only from km 0+000 to km 9+000.

```
<Lines recordCurrent="true" recordVoltage="true"> Set both attributes to true.
  <Line name="A" maxSliceDistance_km="0.5">
    <Conductors> Split the ToProperty at km 9+000 and set the recording to false until the end
of the line.
      <Conductor type="MessengerWire">
        <StartPosition condName="MW" trackID="1" km="0" />
        <ToProperty toPos_km="9" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0" y_m="6.9" />
        <ToProperty toPos_km="85.4" recordCurrent="false" recordVoltage="false" />
      </Conductor>
      <Conductor type="ContactWire">
        <StartPosition condName="CW" trackID="1" km="0" />
        <ToProperty toPos_km="9" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="0" y_m="5.3" />
        <ToProperty toPos_km="85.4" recordCurrent="false" recordVoltage="false" />
      </Conductor>
      <Conductor type="Rail">
        <StartPosition condName="RL" trackID="1" km="0" />
        <ToProperty toPos_km="9" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-0.75" y_m="0" />
        <ToProperty toPos_km="85.4" recordCurrent="false" recordVoltage="false" />
      </Conductor>
      <Conductor type="Rail">
        <StartPosition condName="RR" trackID="1" km="0" />
        <ToProperty toPos_km="9" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0.75" y_m="0" />
        <ToProperty toPos_km="85.4" recordCurrent="false" recordVoltage="false" />
      </Conductor>
      <Conductor type="MessengerWire">
        <StartPosition condName="MW" trackID="2" km="9.750" />
        <ToProperty toPos_km="10.250" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10" y_m="6.9"
recordCurrent="false" recordVoltage="false" />
      </Conductor>
      <Conductor type="ContactWire">
        <StartPosition condName="CW" trackID="2" km="9.750" />
        <ToProperty toPos_km="10.250" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="10" y_m="5.3"
recordCurrent="false" recordVoltage="false" />
      </Conductor>
      <Conductor type="Rail">
        <StartPosition condName="RL" trackID="2" km="9.750" />
        <ToProperty toPos_km="10.250" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="9.25" y_m="0"
recordCurrent="false" recordVoltage="false" />
      </Conductor>
      <Conductor type="Rail">
        <StartPosition condName="RR" trackID="2" km="9.750" />
```

```
        <ToProperty toPos_km="10.250" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10.75" y_m="0"
recordCurrent="false" recordVoltage="false" />
      </Conductor>
      <Conductor type="Earth">
        <StartPosition condName="E" trackID="1" km="0" />
        <ToProperty toPos_km="9" equivalentRadius_mm="450000" r20_Ohm_km="0.0393"
temperature_GradCelsius="20" temperatureCoefficient="0" x_m="0" y_m="-450.0" />
        <ToProperty toPos_km="85.4" recordCurrent="false" recordVoltage="false" />
      </Conductor>
    </Conductors>
```

Set the recording option for the connector slices and leakage to false.

```
<ConnectorSlices recordCurrent="false" recordVoltage="false">
...
<Leakages recordCurrent="false" recordVoltage="false">
```

After we finished the wrong configuration we will do the right configuration. Copy the just created Project-File and add the following:

Add both `Feeder` and `ReturnFeeder` conductors left and right of the substation.

```
<Conductor type="Feeder"> The left feeder with the properties same as a rail.
  <StartPosition condName="LF_l" trackID="1" km="5" />
  <ToProperty
  toPos_km="5.1"
  equivalentRadius_mm="3.45"
  r20_Ohm_km="0.2311"
  temperature_GradCelsius="20"
  temperatureCoefficient="0.004"
  x_m="-4" Make sure to set the cross section for each conductor to a unique location.
  y_m="0" />
</Conductor>
<Conductor type="Feeder"> The right feeder,
  <StartPosition condName="LF_r" trackID="1" km="5.1" />
  <ToProperty toPos_km="6" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-4.2" y_m="0" />
</Conductor>
<Conductor type="ReturnFeeder"> left return feeder and
  <StartPosition condName="RF_l" trackID="1" km="5" />
  <ToProperty toPos_km="5.1" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-4.1" y_m="0" />
</Conductor>
<Conductor type="ReturnFeeder"> right return feeder.
  <StartPosition condName="RF_r" trackID="1" km="5.1" />
  <ToProperty toPos_km="6" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-4.1" y_m="0" />
</Conductor>
```

Then we need to connect the new conductors with the contact wire and rail at km 5+000 respective km 6+000:

```
<Connector name="" zReal_Ohm="0.0001" zImag_Ohm="0">
  <ConductorFrom condName="LF_l" lineID="A" trackID="1" km="5" />
  <ConductorTo condName="CW" lineID="A" trackID="1" km="5" />
</Connector>
<Connector name="" zReal_Ohm="0.0001" zImag_Ohm="0">
  <ConductorFrom condName="RF_l" lineID="A" trackID="1" km="5" />
  <ConductorTo condName="RR" lineID="A" trackID="1" km="5" />
</Connector>
<Connector name="" zReal_Ohm="0.0001" zImag_Ohm="0">
  <ConductorFrom condName="LF_r" lineID="A" trackID="1" km="6" />
  <ConductorTo condName="CW" lineID="A" trackID="1" km="6" />
</Connector>
<Connector name="" zReal_Ohm="0.0001" zImag_Ohm="0">
  <ConductorFrom condName="RF_r" lineID="A" trackID="1" km="6" />
  <ConductorTo condName="RR" lineID="A" trackID="1" km="6" />
</Connector>
```

Finally all infeeds from the substation need to be connected at km 5+100 to the `Feeder` and `ReturnFeeder` conductors.

```
<Busbars>
```

```
  <OCSBB bbName="OCS_BB_1">
    <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Position condName="LF_l" lineID="A" trackID="1" km="5.1" />
      <Switch defaultState="close" name="TSS_5_OCS_Feeder_5.0" />
    </Connector>
  </OCSBB>
  <RailsBB bbName="Rails_BB_1">
    <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Position condName="RF_l" lineID="A" trackID="1" km="5.1" />
      <Switch defaultState="close" name="TSS_5_Rails_Feeder_5.0" />
    </Connector>
  </RailsBB>
  <OCSBB bbName="OCS_BB_2">
    <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Position condName="LF_r" lineID="A" trackID="1" km="5.1" />
      <Switch defaultState="close" name="TSS_5_OCS_Feeder_6.0"></Switch>
    </Connector>
  </OCSBB>
  <RailsBB bbName="Rails_BB_2">
    <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Position condName="RF_r" lineID="A" trackID="1" km="5.1" />
      <Switch defaultState="close" name="TSS_5_Rails_Feeder_6.0" />
    </Connector>
  </RailsBB>
</Busbars>
```

6.7.1.1.3 Simulation

First we run the wrong and then the correct simulation. Note the message at the beginning of the simulation. You can see which currents and voltages are recorded to the database. A "." symbolize a recorded value and a "#" a not recorded value.

6.7.1.1.4 Analysis

For analysis we will use the Excel files CurrentTotal.xls and Voltage.xls.

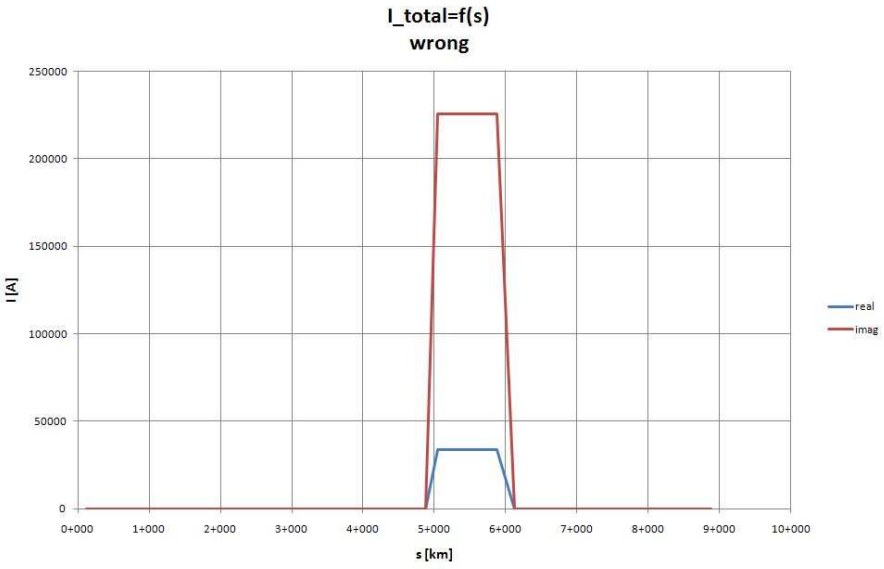


Figure 112 The sum of the conductor current for each section and all time steps with the **wrong** configuration.

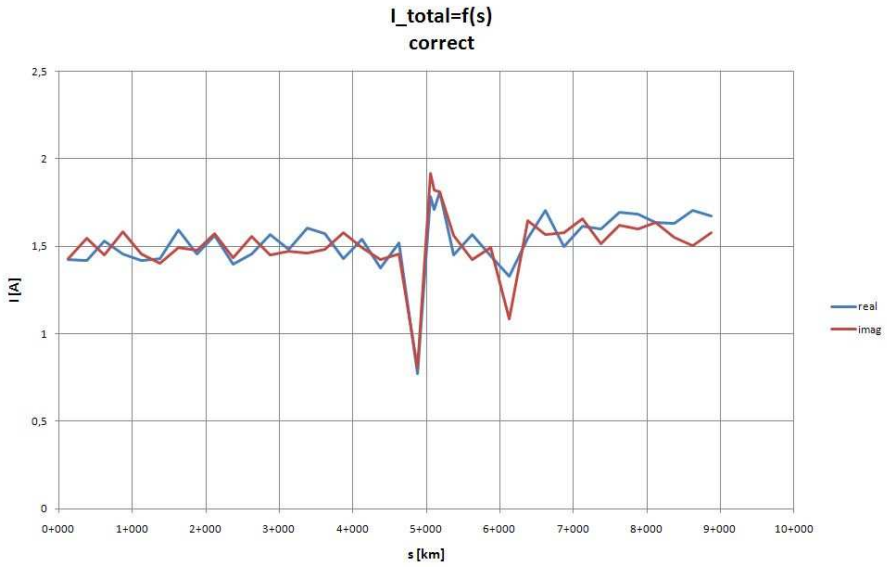


Figure 113 The sum of the conductor current for each section and all time steps with the **correct** configuration.

When we compare both diagrams above we can see the wrong configuration results in a current sum much higher than 0 A. In Figure 113 the resulting current is almost 0 A. The current is not exact 0 A due to numeric rounding during the calculation and analysis.

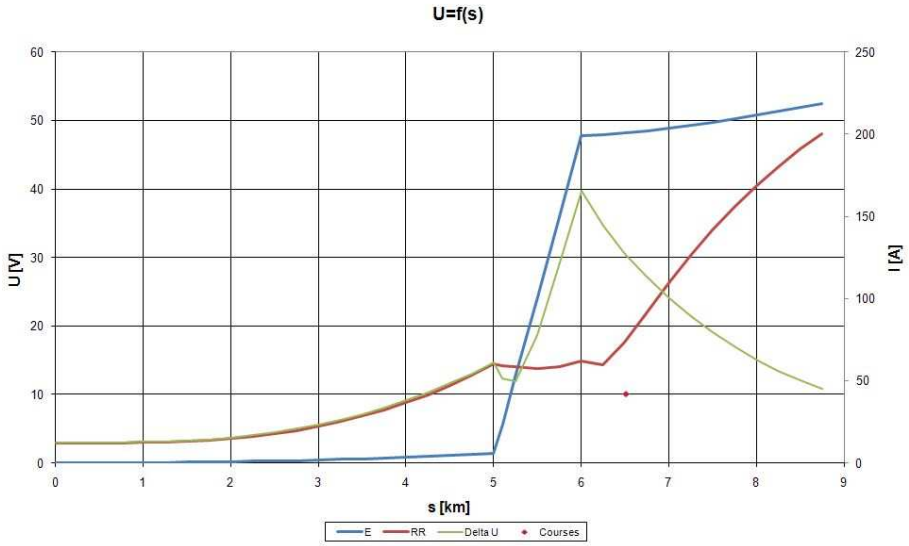


Figure 114 The potential of the earth conductor and rail to the earth node and the touch voltage between the rail RR and earth as result of the wrong configured network at 1:28:37. The right y-axis shows the current of the course.

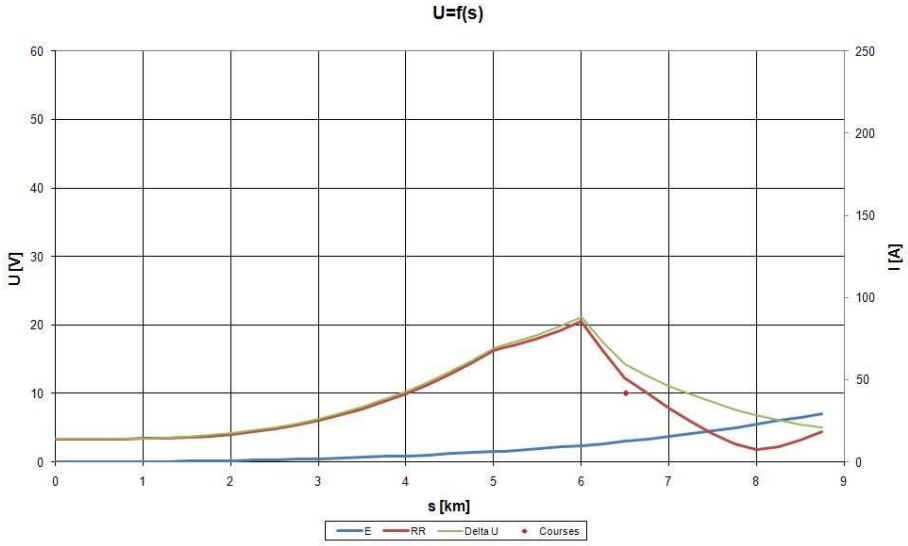


Figure 115 The potential of the earth conductor and rail to the earth node and the touch voltage between the rail RR and earth as result of the correct configured network at 1:28:37. The right y-axis shows the current of the course.

The two figures above show the resulting voltages of the earth conductor and rail RR at 1:28:37. At this time the course CBAl_01 is close to TSS_5. The rail RL has the same voltage as RR because both are connected by very low resistances and therefore not shown.

The difference between both configurations is significant not only for the conductor voltages but also for the touch voltage between them.

6.7.2 Neutral zone tutorial

In this tutorial a 2AC system with neutral zone will be created. The 2AC tutorial was simpler without a neutral zone.

The neutral zone shall be at TSS_5 from km 4+800 until km 5+200 and it shall be possible to feed from one feeding section via the neutral zone to the other feeding section. Furthermore we add an autotransformer station at km 0+000, see Figure 116.

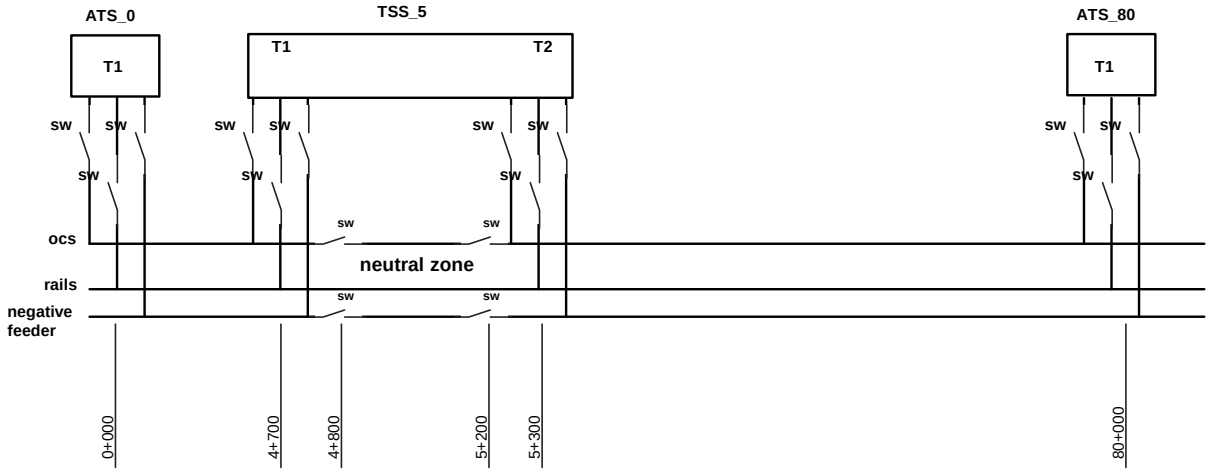


Figure 116 The electrical network model.

To fulfil the constraint that the current sum in each section is always 0 A the neutral zone configuration shall look like in Figure 117.

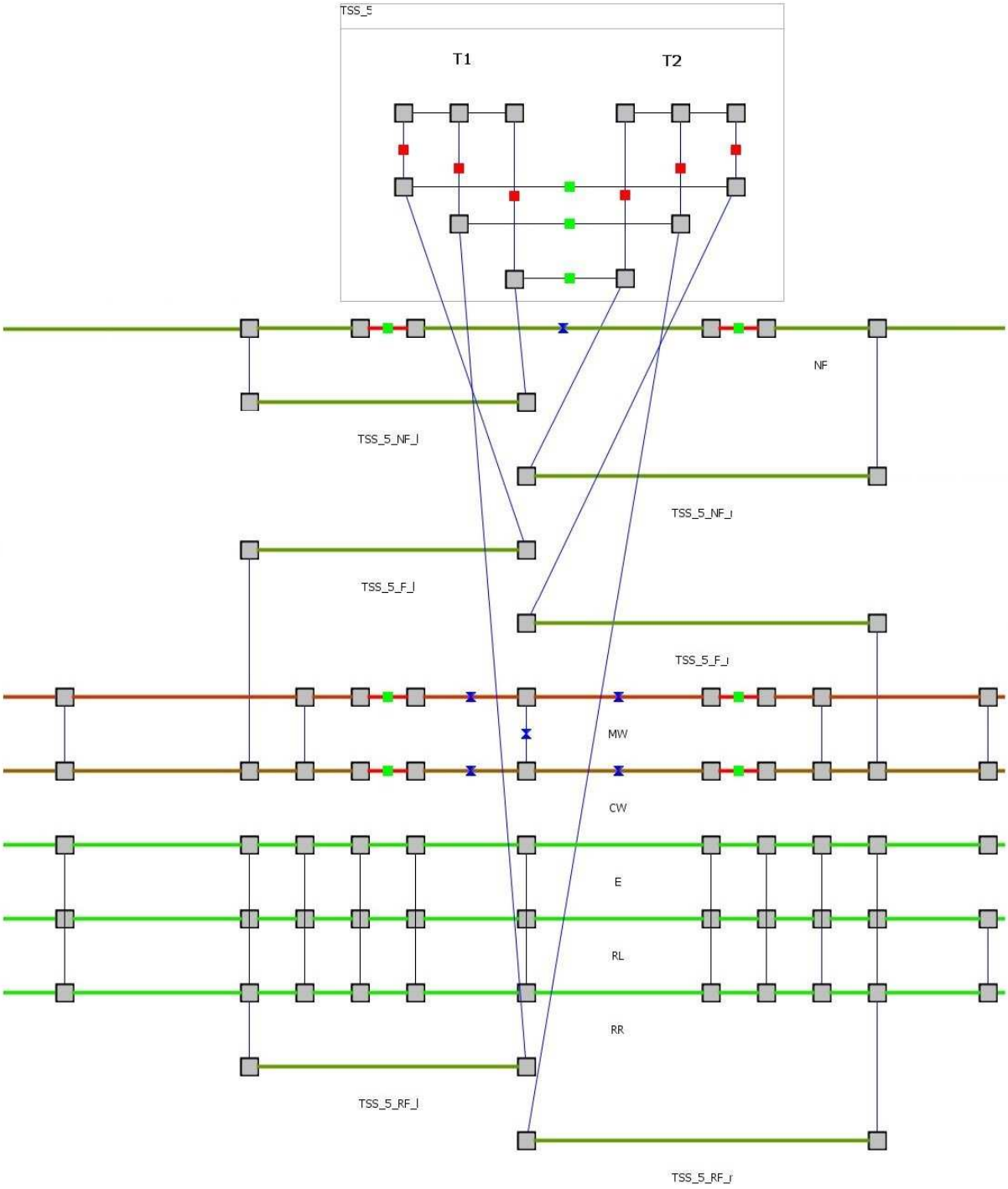


Figure 117 The configuration of a neutral zone of a 2AC system.

6.7.2.1 Configuration

6.7.2.1.1 OpenTrack

We will use the OpenTrack model from the AC tutorial without changes.

Select only the course ABCl_01 and CBAl_01 with long trains.

6.7.2.1.2 OpenPowerNet

We will use the Engine- and correct Project-File from the Substation tutorial in chapter 6.7.1 as the basis.

6.7.2.1.2.1 Engine-File

For this tutorial we don't need to change the Engine-File.

6.7.2.1.2.2 Project-File

First of all we need to add the negative feeder from km 0+000 to km 84+500.

```
<Conductor type="NegativeFeeder">
  <StartPosition condName="NF" trackID="1" km="0" />
  <ToProperty
  toPos_km="9"
  equivalentRadius_mm="8.4"
  r20_Ohm_km="0.1188"
  temperature_GradCelsius="20"
  temperatureCoefficient="0.004"
  x_m="-4"
  y_m="9" />
  <ToProperty toPos_km="80" recordCurrent="false" recordVoltage="false" />
</Conductor>
```

Next we change the `Feeder` and `ReturnFeeder` and add the `NegativeFeeder` conductors parallel to the neutral zone.

Note: The parallel conductors are from km 4+700 to km 5+000 and from km 5+000 to km 5+300.

```
<Conductor type="Feeder">
  <StartPosition condName="TSS_5_F_l" trackID="1" km="4.7" />
  <ToProperty toPos_km="5" equivalentRadius_mm="8.4" r20_Ohm_km="0.1188"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-4" y_m="0" />
</Conductor>
<Conductor type="Feeder">
  <StartPosition condName="TSS_5_F_r" trackID="1" km="5" />
  <ToProperty toPos_km="5.3" equivalentRadius_mm="8.4" r20_Ohm_km="0.1188"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-4" y_m="0" />
</Conductor>
<Conductor type="ReturnFeeder">
  <StartPosition condName="TSS_5_RF_l" trackID="1" km="4.7" />
  <ToProperty toPos_km="5" equivalentRadius_mm="8.4" r20_Ohm_km="0.1188"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-4.1" y_m="0" />
</Conductor>
<Conductor type="ReturnFeeder">
  <StartPosition condName="TSS_5_RF_r" trackID="1" km="5" />
  <ToProperty toPos_km="5.3" equivalentRadius_mm="8.4" r20_Ohm_km="0.1188"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-4.1" y_m="0" />
</Conductor>
Following the two new negative feeder conductors.
<Conductor type="NegativeFeeder">
  <StartPosition condName="TSS_5_NF_l" trackID="1" km="4.7" />
  <ToProperty toPos_km="5" equivalentRadius_mm="8.4" r20_Ohm_km="0.1188"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-4.2" y_m="0" />
```

```
</Conductor>
<Conductor type="NegativeFeeder">
  <StartPosition condName="TSS_5_NF_r" trackID="1" km="5" />
  <ToProperty toPos_km="5.3" equivalentRadius_mm="8.4" r20_Ohm_km="0.1188"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-4.2" y_m="0" />
</Conductor>
```

The changed and added conductors need to be connected to the line. Therfore we need to change and add new connectors.

```
<Connector name="" zReal_Ohm="0.001" zImag_Ohm="0">
  <ConductorFrom condName="TSS_5_F_l" lineID="A" trackID="1" km="4.7" />
  <ConductorTo condName="CW" lineID="A" trackID="1" km="4.7" />
</Connector>
<Connector name="" zReal_Ohm="0.001" zImag_Ohm="0">
  <ConductorFrom condName="TSS_5_F_r" lineID="A" trackID="1" km="5.3" />
  <ConductorTo condName="CW" lineID="A" trackID="1" km="5.3" />
</Connector>
<Connector name="" zReal_Ohm="0.001" zImag_Ohm="0">
  <ConductorFrom condName="TSS_5_RF_l" lineID="A" trackID="1" km="4.7" />
  <ConductorTo condName="RR" lineID="A" trackID="1" km="4.7" />
</Connector>
<Connector name="" zReal_Ohm="0.001" zImag_Ohm="0">
  <ConductorFrom condName="TSS_5_RF_r" lineID="A" trackID="1" km="5.3" />
  <ConductorTo condName="RR" lineID="A" trackID="1" km="5.3" />
</Connector>
These are the connectors to the new negative feeder.
<Connector name="" zReal_Ohm="0.001" zImag_Ohm="0">
  <ConductorFrom condName="TSS_5_NF_l" lineID="A" trackID="1" km="4.7" />
  <ConductorTo condName="NF" lineID="A" trackID="1" km="4.7" />
</Connector>
<Connector name="" zReal_Ohm="0.001" zImag_Ohm="0">
  <ConductorFrom condName="TSS_5_NF_r" lineID="A" trackID="1" km="5.3" />
  <ConductorTo condName="NF" lineID="A" trackID="1" km="5.3" />
</Connector>
```

Instead of isolators we use now conductor switches. Remove the Isolators and add the XML-snipped below.

```
<Switches>
  <ConductorSwitch>
    <Switch defaultState="open" name="TSS_5_4.8_CW" />
    <Position km="4.8" trackID="1" condName="CW" />
  </ConductorSwitch>
  <ConductorSwitch>
    <Switch defaultState="open" name="TSS_5_4.8_MW" />
    <Position km="4.8" trackID="1" condName="MW" />
  </ConductorSwitch>
  <ConductorSwitch>
    <Switch defaultState="open" name="TSS_5_4.8_NF" />
    <Position km="4.8" trackID="1" condName="NF" />
  </ConductorSwitch>
  <ConductorSwitch>
    <Switch defaultState="open" name="TSS_5_5.2_CW" />
    <Position km="5.2" trackID="1" condName="CW" />
  </ConductorSwitch>
  <ConductorSwitch>
    <Switch defaultState="open" name="TSS_5_5.2_MW" />
    <Position km="5.2" trackID="1" condName="MW" />
  </ConductorSwitch>
  <ConductorSwitch>
    <Switch defaultState="open" name="TSS_5_5.2_NF" />
    <Position km="5.2" trackID="1" condName="NF" />
  </ConductorSwitch>
</Switches>
```

After we have done the line configuration we need to add and adapt the substations.

First we add the autotransformer station ATS_0 at km 0+000.

```
<Substation name="ATS_0">
```

```
  <Autotransformer name="T1" nomPower_MVA="5" nomPrimaryVoltage_kV="55"
nomSecondaryVoltage_kV="27.5" noLoadLosses_kW="5" loadLosses_kW="10"
relativeShortCircuitVoltage_percent="1.8" noLoadCurrent_A="0.2">
    <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="ATS_0_T1_OCS" defaultState="close" />
    </OCSBB>
    <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="ATS_0_T1_Rails" defaultState="close" />
    </RailsBB>
    <NegativeFeederBB bbName="NF_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="ATS_0_T1_NF" defaultState="close" />
    </NegativeFeederBB>
  </Autotransformer>
  <Busbars>
    <OCSBB bbName="OCS_BB">
      <Connector name="ATS_0_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="CW" lineID="A" trackID="1" km="0" />
      </Connector>
    </OCSBB>
    <RailsBB bbName="Rails_BB">
      <Connector name="ATS_0_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="RR" lineID="A" trackID="1" km="0" />
      </Connector>
    </RailsBB>
    <NegativeFeederBB bbName="NF_BB">
      <Connector name="ATS_0_NF_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="NF" lineID="A" trackID="1" km="0" />
      </Connector>
    </NegativeFeederBB>
  </Busbars>
</Substation>
```

The TSS_80 shall be replaced by the ATS_80 with same parameter as ATS_0 but connected o the line at km 80+000.

The TSS_5 get now two transformers, 6 busbars and 3 busbar connectors, see the XML snipped below.

```
<Substation name="TSS_5">
  <ThreeWindingTransformer name="T1" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="55" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
    <OCSBB bbName="OCS_BB_1" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="TSS_5_T1_OCS" defaultState="close" />
    </OCSBB>
    <RailsBB bbName="Rails_BB_1" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="TSS_5_T1_Rails" defaultState="close" />
    </RailsBB>
    <NegativeFeederBB bbName="NF_BB_1" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="TSS_5_T1_NF" defaultState="close" />
    </NegativeFeederBB>
  </ThreeWindingTransformer>
  <ThreeWindingTransformer name="T2" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="55" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
    <OCSBB bbName="OCS_BB_2" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="TSS_5_T2_OCS" defaultState="close" />
    </OCSBB>
    <RailsBB bbName="Rails_BB_2" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="TSS_5_T2_Rails" defaultState="close" />
    </RailsBB>
    <NegativeFeederBB bbName="NF_BB_2" z_real_Ohm="0.001" z_imag_Ohm="0">
      <Switch name="TSS_5_T2_NF" defaultState="close" />
    </NegativeFeederBB>
  </ThreeWindingTransformer>
  <Busbars>
    <OCSBB bbName="OCS_BB_1">
      <Connector name="TSS_4.7_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="TSS_5_F_l" lineID="A" trackID="1" km="5" />
      </Connector>
    </OCSBB>
```

```
    <OCSBB bbName="OCS_BB_2">
      <Connector name="TSS_5.3_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="TSS_5_F_r" lineID="A" trackID="1" km="5" />
      </Connector>
    </OCSBB>
    <RailsBB bbName="Rails_BB_1">
      <Connector name="TSS_4.7_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="TSS_5_RF_l" lineID="A" trackID="1" km="5" />
      </Connector>
    </RailsBB>
    <RailsBB bbName="Rails_BB_2">
      <Connector name="TSS_5.3_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="TSS_5_RF_r" lineID="A" trackID="1" km="5" />
      </Connector>
    </RailsBB>
    <NegativeFeederBB bbName="NF_BB_1">
      <Connector name="TSS_4.7_NF_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="TSS_5_NF_l" lineID="A" trackID="1" km="5" />
      </Connector>
    </NegativeFeederBB>
    <NegativeFeederBB bbName="NF_BB_2">
      <Connector name="TSS_5.3_NF_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Position condName="TSS_5_NF_r" lineID="A" trackID="1" km="5" />
      </Connector>
    </NegativeFeederBB>
  </Busbars>
  <OCSBBConnector z_imag_Ohm="0.0" z_real_Ohm="0.001">
    <BusbarFrom bbName="OCS_BB_1" />
    <BusbarTo bbName="OCS_BB_2" />
    <Switch defaultState="open" name="TSS_5_OCS_BB" />
  </OCSBBConnector>
  <RailsBBConnector z_imag_Ohm="0.0" z_real_Ohm="0.001">
    <BusbarFrom bbName="Rails_BB_1" />
    <BusbarTo bbName="Rails_BB_2" />
    <Switch defaultState="open" name="TSS_5_Rails_BB" />
  </RailsBBConnector>
  <NegativeFeederBBConnector z_imag_Ohm="0.0" z_real_Ohm="0.001">
    <BusbarFrom bbName="NF_BB_1" />
    <BusbarTo bbName="NF_BB_2" />
    <Switch defaultState="open" name="TSS_5_NF_BB" />
  </NegativeFeederBBConnector>
</Substation>
```

6.7.2.1.3 Simulation

Run the simulation using the long trains.

6.7.2.1.4 Analysis

After the simulation we will check the total current sum at each section and for all time steps. For this we use the Excel file CurrentTotal.xls. Furthermore we want to check the effect of the neutral zone to the speed of the course.

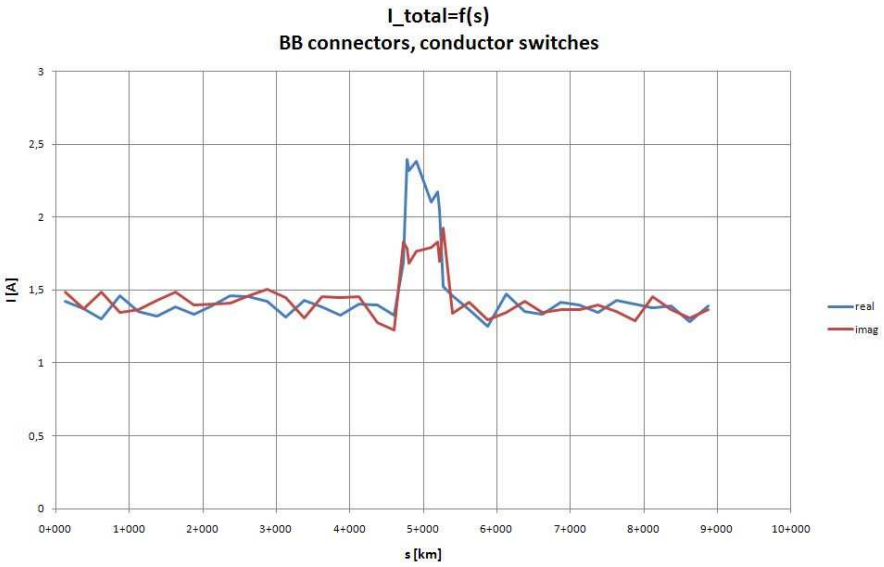


Figure 118 The sum of the current per section of ther whole simulation period.

As we can see from Figure 118 the maximum total current sum is about 2.4 A in the area of the neutral zone. This may look like a lot bus as the simulation runs from 1:00:00 until 1:49:08 in time steps of 1s the number of time steps is 2948. To get the average total current sum per time step we divide 2.4 A by 2948. The result is 0.8 mA and this is very close to 0 A in the context of railway power supplies. Therefore the model of the neutral zone is correct.

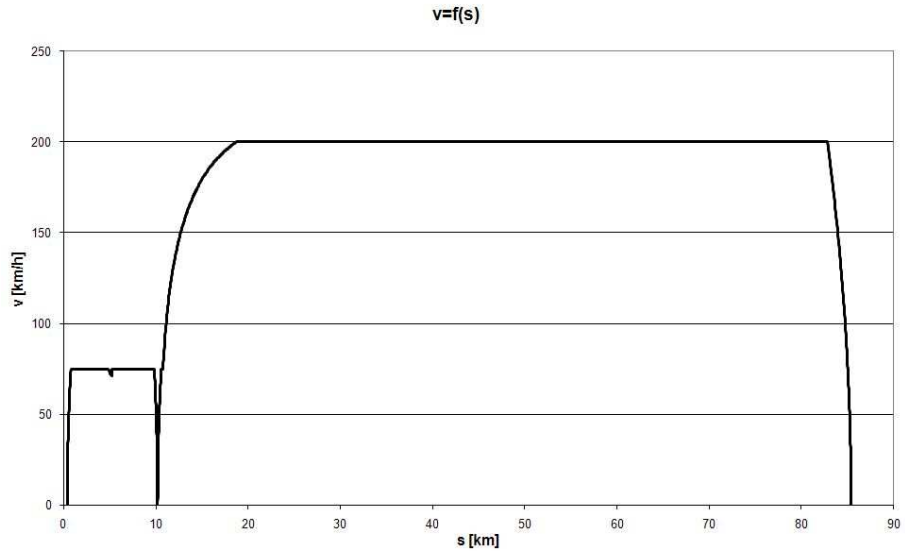


Figure 119 The speed versus location of course ABCl_01.

In the diagram above we can see the speed is reduced in the area of the neutral zone near km 5+000. This is because in the neutral zone is no power supply available.

Usually the courses are powered off before and powered on after they have passed the neutral zone. This power off and on is possible by the power signals in OpenTrack. Please see the OpenTrack documentation for details.

6.7.3 AC-DC networks tutorial

In this tutorial we will create a project file with an AC and a DC network. The engines shall have to propulsion system. One propulsion system shall be for 25 kV 50 Hz and the other for 3 kV DC.

Engine Property	AC	DC
F_{max}	250 kN	200 kN
P_{max}	5.56 MW	3.89 MW

Table 12 The engine properties of the AC-DC tutorial.

Network Property	AC	DC
Substation	km 45+000	km 5+000
Chainage	track “1” from km 9+750 to km 85+400	track “1” from km 0+000 to km 9+750 and track “2” from km 9+750 to km 10+250
Line feeder	none	yes from km 0+000 to km 9+750

Table 13 The network properties of the AC-DC tutorial.

6.7.3.1 Configuration

6.7.3.1.1 OpenTrack

The bases are the configuration files from the AC tutorial in chapter 6.2.

We need to:

- Change the propulsion system of the infrastructure (Figure 120) and
- Add the 3 kV DC propulsion system to “Engine1” (Figure 121).

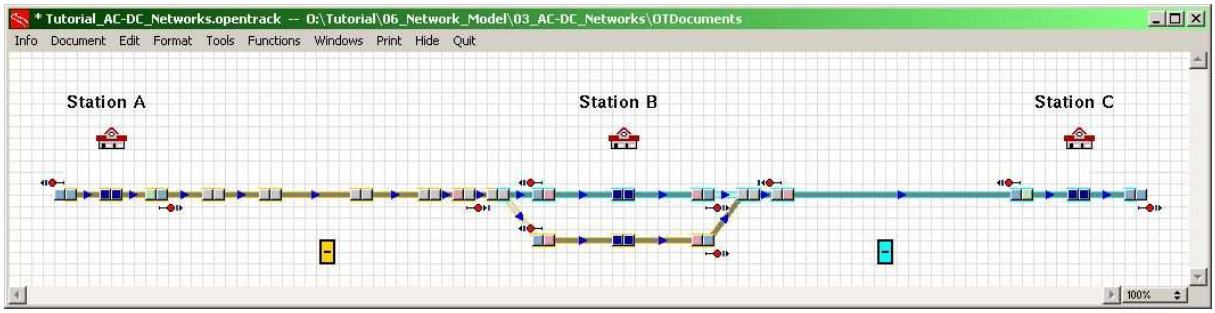


Figure 120 The OpenTrack infrastructure indicating the AC (blue) and DC (orange) power supply system.

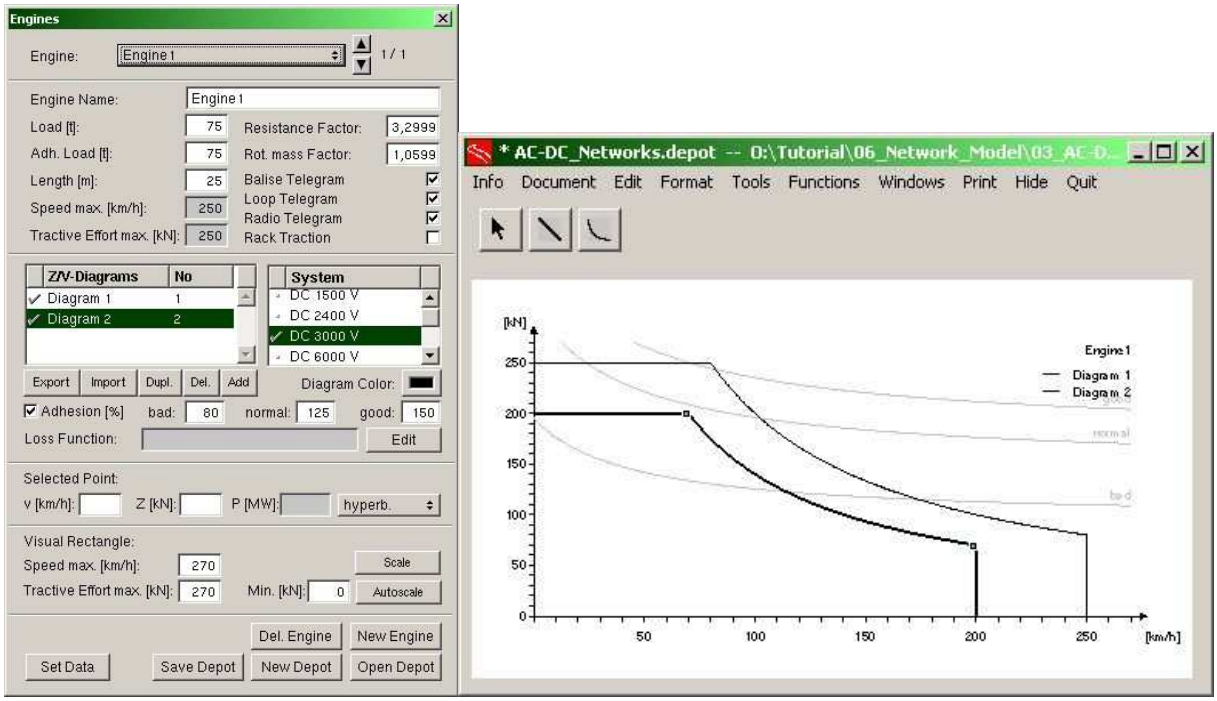


Figure 121 The engine configuration in OpenTrack with two propulsion systems.

6.7.3.1.2 OpenPowerNet

In OpenPowerNet we need also both propulsion systems in order to run the same engine on both propulsion systems.

6.7.3.1.2.1 Engine-File

The basis shall be the Engine-File from the AC tutorial in chapter 6.2. To this engine file we add the DC propulsion system with the properties listed in Table 12, see XML snippet below.

```
<propulsion
supply="DC 3000V"
transmission="electric"
engine="electric"
power="3890"
maxTractEffort="200"
totalTractEfficiency="90"
totalBrakeEfficiency="90">
  <auxSupply typeStr="all" constPower="100"/>
</propulsion>
```

6.7.3.1.2.2 Project-File

As the basis we will use the Project-File from the AC tutorial in chapter 6.2.

First we add the configuration of the DC propulsion system to the engine.

```
<Propulsion engine="electric" supply="DC 3000V" brakeCurrentLimitation="none"
tractiveCurrentLimitation="none" useAuxPower="true" fourQuadrantChopperPhi="none"
regenerativeBrake="none" tractiveEffort="maxPower/maxTractEffort">
  <MeanEfficiency />
</Propulsion>
```

It is the same as for AC but the attribute `supply` has a different value.

Second is the configuration of the electrical networks.

The DC network:

```
<Network name="A-B" use="true"
voltage_kV="3" Set the voltage and
frequency_Hz="0" frequency for DC.
recordVoltage="true" recordCurrent="true">
  <Lines recordCurrent="false+sub" recordVoltage="false+sub">
    <Line name="A" maxSliceDistance_km="0.5">
      <Conductors> First the conductors for track 1 from km 0+000 to km 9+750.
        <Conductor type="Feeder">
          <StartPosition condName="LF" trackID="1" km="0" />
          <ToProperty toPos_km="9.750" equivalentRadius_mm="8.4" r20_Ohm_km="0.1188"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-4" y_m="9" />
        </Conductor>
        <Conductor type="MessengerWire">
          <StartPosition condName="MW" trackID="1" km="0" />
          <ToProperty toPos_km="9.750" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0" y_m="6.9" />
        </Conductor>
        <Conductor type="ContactWire">
          <StartPosition condName="CW" trackID="1" km="0" />
          <ToProperty toPos_km="9.750" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="0" y_m="5.3" />
        </Conductor>
        <Conductor type="Rail">
          <StartPosition condName="RL" trackID="1" km="0" />
          <ToProperty toPos_km="9.750" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-0.75" y_m="0" />
        </Conductor>
        <Conductor type="Rail">
          <StartPosition condName="RR" trackID="1" km="0" />
          <ToProperty toPos_km="9.750" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0.75" y_m="0" />
        </Conductor> Then the conductors for track 2 from km 9+750 to km 10+250.
        <Conductor type="MessengerWire">
          <StartPosition condName="MW" trackID="2" km="9.750" />
          <ToProperty toPos_km="10.250" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10" y_m="6.9" />
        </Conductor>
        <Conductor type="ContactWire">
          <StartPosition condName="CW" trackID="2" km="9.750" />
          <ToProperty toPos_km="10.250" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="10" y_m="5.3" />
        </Conductor>
        <Conductor type="Rail">
          <StartPosition condName="RL" trackID="2" km="9.750" />
          <ToProperty toPos_km="10.250" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="9.25" y_m="0" />
        </Conductor>
        <Conductor type="Rail">
          <StartPosition condName="RR" trackID="2" km="9.750" />
          <ToProperty toPos_km="10.250" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10.75" y_m="0" />
        </Conductor> Last but not least the earth wire.
        <Conductor type="Earth">
          <StartPosition condName="E" trackID="1" km="0" />
          <ToProperty toPos_km="10.250" equivalentRadius_mm="450000" r20_Ohm_km="0.0393"
temperature_GradCelsius="20" temperatureCoefficient="0" x_m="0" y_m="-450.0" />
        </Conductor>
      </Conductors>
      <ConnectorSlices> The connectors between contact and messenger wire and
        <ConnectorSlice name="dropper, track 1" firstPos_km="0" lastPos_km="9.750"
maxDistance_km="0.25">
          <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
            <ConductorFrom condName="MW" trackID="1" />
            <ConductorTo condName="CW" trackID="1" />
          </Connector>
        </ConnectorSlice>
        <ConnectorSlice name="dropper, track 2" firstPos_km="9.750" lastPos_km="10.250"
maxDistance_km="0.25">
          <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
            <ConductorFrom condName="MW" trackID="2" />
```

```
            <ConductorTo condName="CW" trackID="2" />
          </Connector>
        </ConnectorSlice>
        <ConnectorSlice name="rail connector, track 1" firstPos_km="0" lastPos_km="9.750"
maxDistance_km="0.25">
          <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
            <ConductorFrom condName="RL" trackID="1" />
            <ConductorTo condName="RR" trackID="1" />
          </Connector>
        </ConnectorSlice>
        <ConnectorSlice name="rail connector, track 2" firstPos_km="9.750" lastPos_km="10.250"
maxDistance_km="0.25">
          <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
            <ConductorFrom condName="RL" trackID="2" />
            <ConductorTo condName="RR" trackID="2" />
          </Connector>
        </ConnectorSlice> line feeder top contact wire.
        <ConnectorSlice name="line feeder to CW" firstPos_km="0" lastPos_km="9.750"
maxDistance_km="0.25">
          <Connector zReal_Ohm="0.000594" zImag_Ohm="0">
            <ConductorFrom condName="LF" trackID="1" />
            <ConductorTo condName="CW" trackID="1" />
          </Connector>
        </ConnectorSlice>
      </ConnectorSlices>
      <Leakages> The leakages for both tracks.
        <Leakage firstPos_km="0" lastPos_km="9.750" yReal_S_km="0.1" yImag_S_km="0">
          <ConductorFrom condName="RL" trackID="1" />
          <ConductorTo condName="E" trackID="1" />
        </Leakage>
        <Leakage firstPos_km="0" lastPos_km="9.750" yReal_S_km="0.1" yImag_S_km="0">
          <ConductorFrom condName="RR" trackID="1" />
          <ConductorTo condName="E" trackID="1" />
        </Leakage>
        <Leakage firstPos_km="9.750" lastPos_km="10.250" yReal_S_km="0.1" yImag_S_km="0">
          <ConductorFrom condName="RL" trackID="2" />
          <ConductorTo condName="E" trackID="1" />
        </Leakage>
        <Leakage firstPos_km="9.750" lastPos_km="10.250" yReal_S_km="0.1" yImag_S_km="0">
          <ConductorFrom condName="RR" trackID="2" />
          <ConductorTo condName="E" trackID="1" />
        </Leakage>
      </Leakages>
    </Line>
  </Lines> These are the connectors from track 1 to track 2 conductors.
  <Connectors recordCurrent="false+sub" recordVoltage="false+sub">
    <Connector name="MW track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
      <ConductorFrom condName="MW" lineID="A" trackID="1" km="9.750" />
      <ConductorTo condName="MW" lineID="A" trackID="2" km="9.750" />
    </Connector>
    <Connector name="CW track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
      <ConductorFrom condName="CW" lineID="A" trackID="1" km="9.750" />
      <ConductorTo condName="CW" lineID="A" trackID="2" km="9.750" />
    </Connector>
    <Connector name="RL track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
      <ConductorFrom condName="RL" lineID="A" trackID="1" km="9.750" />
      <ConductorTo condName="RL" lineID="A" trackID="2" km="9.750" />
    </Connector>
    <Connector name="RR track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
      <ConductorFrom condName="RR" lineID="A" trackID="1" km="9.750" />
      <ConductorTo condName="RR" lineID="A" trackID="2" km="9.750" />
    </Connector>
  </Connectors>
  <Substations>
    <Substation name="TSS_5"> The substation at km 5+000 with rectifier.
      <Rectifier name="R1" internalResistance_Ohm="0.01" nomVoltage_kV="3.3"
energyRecovery="false">
        <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0" />
        <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0" />
      </Rectifier>
      <Busbars>
```

```
        <OCSBB bbName="OCS_BB">
          <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
            <Position condName="CW" lineID="A" trackID="1" km="5" />
          </Connector>
          <Connector name="TSS_5_LF_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
            <Position condName="LF" lineID="A" trackID="1" km="5" />
          </Connector>
        </OCSBB>
        <RailsBB bbName="Rails_BB">
          <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
            <Position condName="RR" lineID="A" trackID="1" km="5" />
          </Connector>
        </RailsBB>
      </Busbars>
    </Substation>
  </Substations>
  <Earth condName="E" lineID="A" trackID="1" km="0" />
</Network>
```

The AC network:

```
<Network name="B-C" use="true"
voltage_kV="25" The nominal voltage and
frequency_Hz="50" frequency for the AC network.
recordVoltage="true" recordCurrent="true">
  <Lines recordCurrent="false+sub" recordVoltage="false+sub">
    <Line name="A" maxSliceDistance_km="0.5">
      <Conductors> The conductors for track 1 from km 9+750 to km 85+400.
        <Conductor type="MessengerWire">
          <StartPosition condName="MW" trackID="1" km="9.750" />
          <ToProperty toPos_km="85.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0" y_m="6.9" />
        </Conductor>
        <Conductor type="ContactWire">
          <StartPosition condName="CW" trackID="1" km="9.750" />
          <ToProperty toPos_km="85.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="0" y_m="5.3" />
        </Conductor>
        <Conductor type="Rail">
          <StartPosition condName="RL" trackID="1" km="9.750" />
          <ToProperty toPos_km="85.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-0.75" y_m="0" />
        </Conductor>
        <Conductor type="Rail">
          <StartPosition condName="RR" trackID="1" km="9.750" />
          <ToProperty toPos_km="85.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0.75" y_m="0" />
        </Conductor>
        <Conductor type="Earth">
          <StartPosition condName="E" trackID="1" km="9.750" />
          <ToProperty toPos_km="85.4" equivalentRadius_mm="450000" r20_Ohm_km="0.0393"
temperature_GradCelsius="20" temperatureCoefficient="0" x_m="0" y_m="-450.0" />
        </Conductor>
      </Conductors>
      <ConnectorSlices> The connectors between contact and messenger wire.
        <ConnectorSlice name="dropper, track 1" firstPos_km="9.750" lastPos_km="85.4"
maxDistance_km="0.25">
          <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
            <ConductorFrom condName="MW" trackID="1" />
            <ConductorTo condName="CW" trackID="1" />
          </Connector>
        </ConnectorSlice>
        <ConnectorSlice name="rail connector, track 1" firstPos_km="9.750" lastPos_km="85.4"
maxDistance_km="0.25">
          <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
            <ConductorFrom condName="RL" trackID="1" />
            <ConductorTo condName="RR" trackID="1" />
          </Connector>
        </ConnectorSlice>
      </ConnectorSlices>
      <Leakages> The leakages for the track.
        <Leakage firstPos_km="9.750" lastPos_km="85.4" yReal_S_km="0.1" yImag_S_km="0">
```

```
          <ConductorFrom condName="RL" trackID="1" />
          <ConductorTo condName="E" trackID="1" />
        </Leakage>
        <Leakage firstPos_km="9.750" lastPos_km="85.4" yReal_S_km="0.1" yImag_S_km="0">
          <ConductorFrom condName="RR" trackID="1" />
          <ConductorTo condName="E" trackID="1" />
        </Leakage>
      </Leakages>
    </Line>
  </Lines>
  <Substations> The substation at km 45+000 with two winding transformer.
    <Substation name="TSS_45">
      <TwoWindingTransformer name="T1" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="27.5" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
        <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Switch name="TSS_45_T1_OCS" defaultState="close" />
        </OCSBB>
        <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Switch name="TSS_45_T1_Rails" defaultState="close" />
        </RailsBB>
      </TwoWindingTransformer>
      <Busbars>
        <OCSBB bbName="OCS_BB">
          <Connector name="TSS_45_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
            <Position condName="CW" lineID="A" trackID="1" km="45" />
          </Connector>
        </OCSBB>
        <RailsBB bbName="Rails_BB">
          <Connector name="TSS_45_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
            <Position condName="RR" lineID="A" trackID="1" km="45" />
          </Connector>
        </RailsBB>
      </Busbars>
    </Substation>
  </Substations>
  <Earth condName="E" lineID="A" trackID="1" km="9.750" />
</Network>
```

6.7.3.1.3 Simulation

Run the simulation with long trains only.

6.7.3.1.4 Analysis

For analysis we use the Excel file EngineAll.xls and Engine.xls.

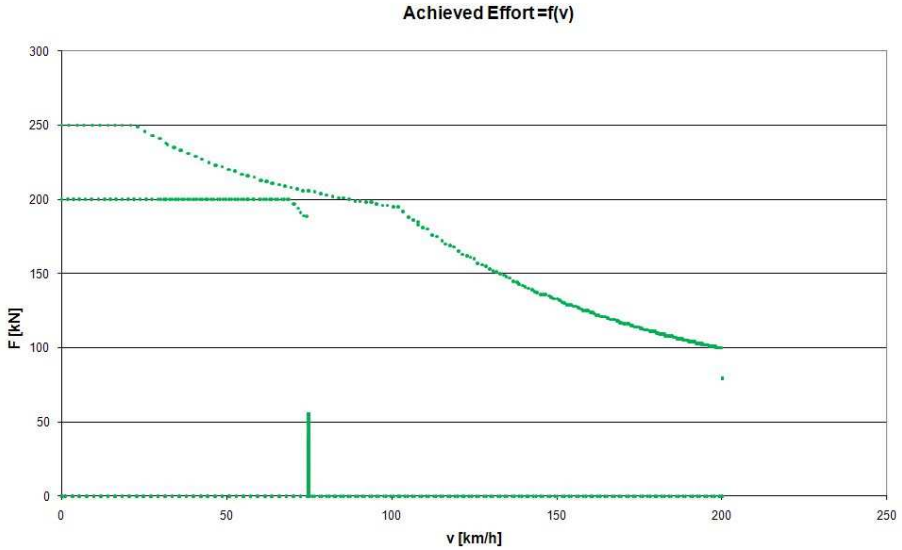


Figure 122 The achieved effort of the engines in the DC and AC network.

In the diagram above we can see very well the two different efforts versus speed characteristics. The higher curve belongs to the AC and the lower to the DC propulsion system.

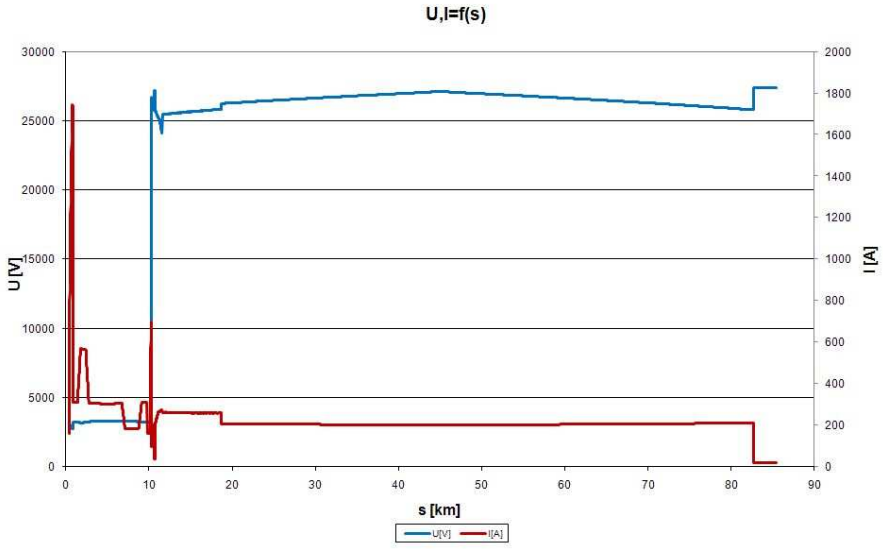


Figure 123 The line voltage and current at pantograph of course ABCl_01.

In Figure 123 are the curves for voltage and current in both electrical networks. The line voltage of the two systems is significant different and the location of the system change over visible.

6.7.4 Network with multiple lines, points and crossings tutorial

In This tutorial we will create an OpenTrack infrastructure with two lines and multiple points and one crossing. For the simulation of the electrical power supply we create a network also with two lines and 3 substations.

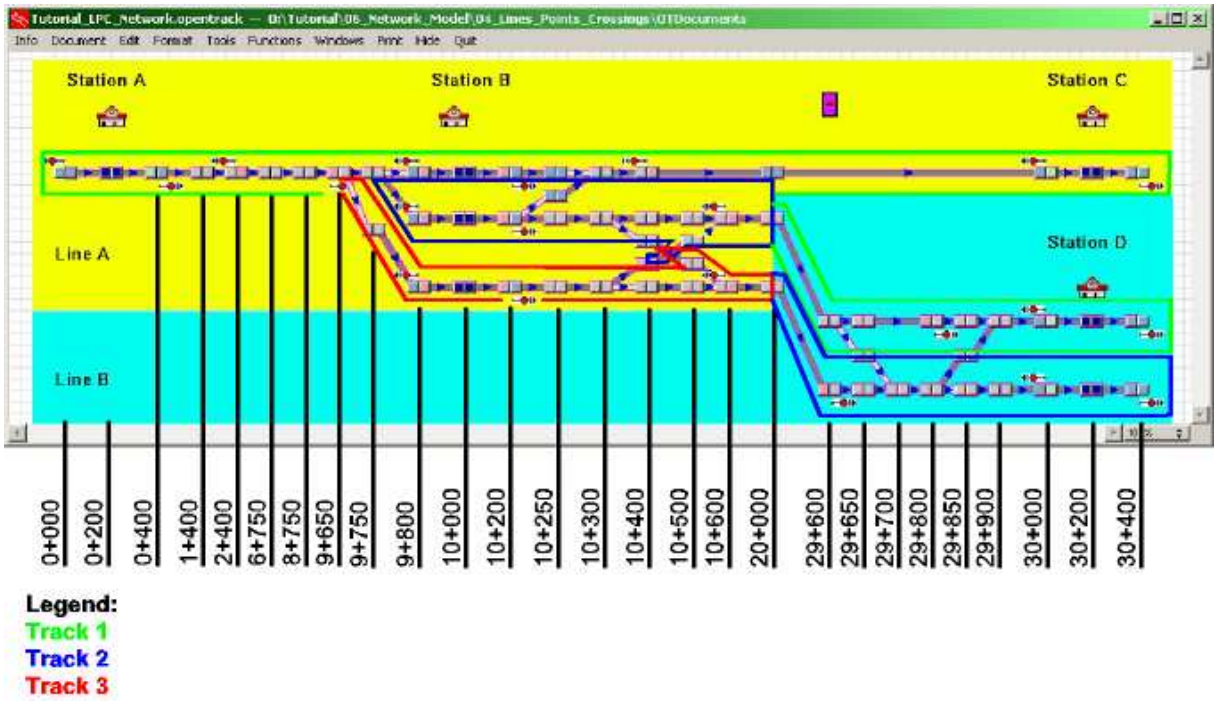


Figure 124 The OpenTrack infrastructure with chaininage, line and track names.

Property	Value				
Signal	km 29+600 track 2: set sight distance to 10000m				
Timetable	**Course**	**Station A**	**Station B**	**Station C**	**Station D**
	ABCl_0100	Start 01:00:00	Stop 300s, track 2	Terminate	
	CBAl_0100	Terminate	Stop 600s, track 1	Start 01:00:00	
	DBAl_1000	Terminate	Stop 60s, track 3		Start 01:00:00, track 1
	ABDl_0110	Start 01:10:00	Stop 60s, track 2		Terminate, track 2
	DBAl_1015	Terminate	Stop 60s, track 2		Start 01:15:00, track 1

Table 14 OpenTrack infrastructure properties and timetable.

Property	Line A	Line B
Substation	km 5+000 & km 25+000	km 25+000
Power system	25 kV 50 Hz	

Table 15 OpenPowerNet network properties.

6.7.4.1 Configuration

6.7.4.1.1 OpenTrack

As the basis we take the data from the AC tutorial. The tracks to be added have no gradient or radius.

Create the tracks and use the information from Figure 124.

Note:

- The track names of the crossing and the cross-over are the same as for the main line tracks.

The electrical network model shall be simplified and the catenary for the crossing tracks and the cross-over tracks shall not be modelled. Only the main tracks shall have a catenary model. Therefore the positions within the crossing and cross-over have to be mapped to the main tracks. A position is always the triplet of line name, track name and chainage.

Create all paths, routes and itineraries to run the trains as listed in Table 14.

Note:

- The courses drive by default at the right track!

6.7.4.1.2 OpenPowerNet

We will use the Engine- and Project-File from the AC tutorial as the basis.

6.7.4.1.2.1 Engine-File

For this tutorial we don't need to change the Engine-File.

6.7.4.1.2.2 Project-File

From the AC tutorial we will used the substation configuration, the properties of the conductors, connectors and connector slices. We need to change the beginning and the end of the conductors and slices.

The configuration of the engine model does not need to be changed.

First the configuration of line A:

```
<Line name="A" maxSliceDistance_km="0.5">
  <Conductors>
The conductor configuration for track 1.
    <Conductor type="MessengerWire">
      <StartPosition condName="MW" trackID="1" km="0" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0" y_m="6.9" />
    </Conductor>
    <Conductor type="ContactWire">
      <StartPosition condName="CW" trackID="1" km="0" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="0" y_m="5.3" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition condName="RL" trackID="1" km="0" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-0.75" y_m="0" />
```

```
    </Conductor>
    <Conductor type="Rail">
      <StartPosition condName="RR" trackID="1" km="0" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0.75" y_m="0" />
    </Conductor>
The conductor configuration for track 2.
    <Conductor type="MessengerWire">
      <StartPosition condName="MW" trackID="2" km="9.750" />
      <ToProperty toPos_km="20.000" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10" y_m="6.9" />
    </Conductor>
    <Conductor type="ContactWire">
      <StartPosition condName="CW" trackID="2" km="9.750" />
      <ToProperty toPos_km="20.000" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="10" y_m="5.3" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition condName="RL" trackID="2" km="9.750" />
      <ToProperty toPos_km="20.000" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="9.25" y_m="0" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition condName="RR" trackID="2" km="9.750" />
      <ToProperty toPos_km="20.000" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10.75" y_m="0" />
    </Conductor>
The conductor configuration for track 3.
    <Conductor type="MessengerWire">
      <StartPosition condName="MW" trackID="3" km="9.650" />
      <ToProperty toPos_km="20.000" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="20" y_m="6.9" />
    </Conductor>
    <Conductor type="ContactWire">
      <StartPosition condName="CW" trackID="3" km="9.650" />
      <ToProperty toPos_km="20.000" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="20" y_m="5.3" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition condName="RL" trackID="3" km="9.650" />
      <ToProperty toPos_km="20.000" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="19.25" y_m="0" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition condName="RR" trackID="3" km="9.650" />
      <ToProperty toPos_km="20.000" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="20.75" y_m="0" />
    </Conductor>
The earth conductor.
    <Conductor type="Earth">
      <StartPosition condName="E" trackID="1" km="0" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="450000" r20_Ohm_km="0.0393"
temperature_GradCelsius="20" temperatureCoefficient="0" x_m="0" y_m="-450.0" />
    </Conductor>
  </Conductors>
  <ConnectorSlices>
The dropper configuration for track 1.
    <ConnectorSlice name="dropper, track 1" firstPos_km="0" lastPos_km="30.4"
maxDistance_km="0.25">
      <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
        <ConductorFrom condName="MW" trackID="1" />
        <ConductorTo condName="CW" trackID="1" />
      </Connector>
    </ConnectorSlice>
The dropper configuration for track 2.
    <ConnectorSlice name="dropper, track 2" firstPos_km="9.750" lastPos_km="20.000"
maxDistance_km="0.25">
      <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
        <ConductorFrom condName="MW" trackID="2" />
        <ConductorTo condName="CW" trackID="2" />
      </Connector>
```

```
    </ConnectorSlice>
The dropper configuration for track 3.
    <ConnectorSlice name="dropper, track 3" firstPos_km="9.650" lastPos_km="20.000"
maxDistance_km="0.25">
      <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
        <ConductorFrom condName="MW" trackID="3" />
        <ConductorTo condName="CW" trackID="3" />
      </Connector>
    </ConnectorSlice>
The rail connector configuration for track 1.
    <ConnectorSlice name="rail connector, track 1" firstPos_km="0" lastPos_km="30.4"
maxDistance_km="0.25">
      <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
        <ConductorFrom condName="RL" trackID="1" />
        <ConductorTo condName="RR" trackID="1" />
      </Connector>
    </ConnectorSlice>
The rail connector configuration for track 2.
    <ConnectorSlice name="rail connector, track 2" firstPos_km="9.750" lastPos_km="20.000"
maxDistance_km="0.25">
      <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
        <ConductorFrom condName="RL" trackID="2" />
        <ConductorTo condName="RR" trackID="2" />
      </Connector>
    </ConnectorSlice>
The rail connector configuration for track 3.
    <ConnectorSlice name="rail connector, track 3" firstPos_km="9.650" lastPos_km="20.000"
maxDistance_km="0.25">
      <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
        <ConductorFrom condName="RL" trackID="3" />
        <ConductorTo condName="RR" trackID="3" />
      </Connector>
    </ConnectorSlice>
  </ConnectorSlices>
  <Leakages>
The leakage configuration for track 1.
    <Leakage firstPos_km="0" lastPos_km="30.4" yReal_S_km="0.1" yImag_S_km="0">
      <ConductorFrom condName="RL" trackID="1" />
      <ConductorTo condName="E" trackID="1" />
    </Leakage>
    <Leakage firstPos_km="0" lastPos_km="30.4" yReal_S_km="0.1" yImag_S_km="0">
      <ConductorFrom condName="RR" trackID="1" />
      <ConductorTo condName="E" trackID="1" />
    </Leakage>
The leakage configuration for track 2.
    <Leakage firstPos_km="9.750" lastPos_km="20.00" yReal_S_km="0.1" yImag_S_km="0">
      <ConductorFrom condName="RL" trackID="2" />
      <ConductorTo condName="E" trackID="1" />
    </Leakage>
    <Leakage firstPos_km="9.750" lastPos_km="20.000" yReal_S_km="0.1" yImag_S_km="0">
      <ConductorFrom condName="RR" trackID="2" />
      <ConductorTo condName="E" trackID="1" />
    </Leakage>
The leakage configuration for track 3.
    <Leakage firstPos_km="9.650" lastPos_km="20.00" yReal_S_km="0.1" yImag_S_km="0">
      <ConductorFrom condName="RL" trackID="3" />
      <ConductorTo condName="E" trackID="1" />
    </Leakage>
    <Leakage firstPos_km="9.650" lastPos_km="20.000" yReal_S_km="0.1" yImag_S_km="0">
      <ConductorFrom condName="RR" trackID="3" />
      <ConductorTo condName="E" trackID="1" />
    </Leakage>
  </Leakages>
</Line>
```

Configuration of line B:

```
<Line name="B" maxSliceDistance_km="0.5">
  <Conductors>
The conductor configuration for track 1.
```

```
    <Conductor type="MessengerWire">
      <StartPosition condName="MW" trackID="1" km="20" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0" y_m="6.9" />
    </Conductor>
    <Conductor type="ContactWire">
      <StartPosition condName="CW" trackID="1" km="20" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="0" y_m="5.3" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition condName="RL" trackID="1" km="20" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-0.75" y_m="0" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition condName="RR" trackID="1" km="20" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0.75" y_m="0" />
    </Conductor>
The conductor configuration for track 2.
    <Conductor type="MessengerWire">
      <StartPosition condName="MW" trackID="2" km="20" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10" y_m="6.9" />
    </Conductor>
    <Conductor type="ContactWire">
      <StartPosition condName="CW" trackID="2" km="20" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="10" y_m="5.3" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition condName="RL" trackID="2" km="20" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="9.25" y_m="0" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition condName="RR" trackID="2" km="20" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10.75" y_m="0" />
    </Conductor>
The earth conductor.
    <Conductor type="Earth">
      <StartPosition condName="E" trackID="1" km="20" />
      <ToProperty toPos_km="30.4" equivalentRadius_mm="450000" r20_Ohm_km="0.0393"
temperature_GradCelsius="20" temperatureCoefficient="0" x_m="0" y_m="-450.0" />
    </Conductor>
  </Conductors>
  <ConnectorSlices>
The dropper configuration for track 1.
    <ConnectorSlice name="dropper, track 1" firstPos_km="20" lastPos_km="30.4"
maxDistance_km="0.25">
      <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
        <ConductorFrom condName="MW" trackID="1" />
        <ConductorTo condName="CW" trackID="1" />
      </Connector>
    </ConnectorSlice>
The dropper configuration for track 2.
    <ConnectorSlice name="dropper, track 2" firstPos_km="20" lastPos_km="30.4"
maxDistance_km="0.25">
      <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
        <ConductorFrom condName="MW" trackID="2" />
        <ConductorTo condName="CW" trackID="2" />
      </Connector>
    </ConnectorSlice>
The rail connector configuration for track 1.
    <ConnectorSlice name="rail connector, track 1" firstPos_km="20" lastPos_km="30.4"
maxDistance_km="0.25">
      <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
        <ConductorFrom condName="RL" trackID="1" />
        <ConductorTo condName="RR" trackID="1" />
```

```
      </Connector>
    </ConnectorSlice>
The rail connector configuration for track 2.
    <ConnectorSlice name="rail connector, track 2" firstPos_km="20" lastPos_km="30.4"
maxDistance_km="0.25">
      <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
        <ConductorFrom condName="RL" trackID="2" />
        <ConductorTo condName="RR" trackID="2" />
      </Connector>
    </ConnectorSlice>
  </ConnectorSlices>
  <Leakages>
The leakage configuration for track 1.
    <Leakage firstPos_km="20" lastPos_km="30.4" yReal_S_km="0.1" yImag_S_km="0">
      <ConductorFrom condName="RL" trackID="1" />
      <ConductorTo condName="E" trackID="1" />
    </Leakage>
    <Leakage firstPos_km="20" lastPos_km="30.4" yReal_S_km="0.1" yImag_S_km="0">
      <ConductorFrom condName="RR" trackID="1" />
      <ConductorTo condName="E" trackID="1" />
    </Leakage>
The leakage configuration for track 2.
    <Leakage firstPos_km="20" lastPos_km="30.4" yReal_S_km="0.1" yImag_S_km="0">
      <ConductorFrom condName="RL" trackID="2" />
      <ConductorTo condName="E" trackID="1" />
    </Leakage>
    <Leakage firstPos_km="20" lastPos_km="30.4" yReal_S_km="0.1" yImag_S_km="0">
      <ConductorFrom condName="RR" trackID="2" />
      <ConductorTo condName="E" trackID="1" />
    </Leakage>
  </Leakages>
</Line>
```

After the configuration of the conductors for both lines and all tracks the electrical connection between the lines and tracks shall be configured.

```
The electrical connection of track 1 and 3 at km 9+650.
<Connectors>
  <Connector name="MW track 1-3, km 9+650" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="MW" lineID="A" trackID="1" km="9.650" />
    <ConductorTo condName="MW" lineID="A" trackID="3" km="9.650" />
  </Connector>
  <Connector name="CW track 1-3, km 9+650" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="CW" lineID="A" trackID="1" km="9.650" />
    <ConductorTo condName="CW" lineID="A" trackID="3" km="9.650" />
  </Connector>
  <Connector name="RL track 1-3, km 9+650" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="RL" lineID="A" trackID="1" km="9.650" />
    <ConductorTo condName="RL" lineID="A" trackID="3" km="9.650" />
  </Connector>
  <Connector name="RR track 1-3, km 9+650" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="RR" lineID="A" trackID="1" km="9.650" />
    <ConductorTo condName="RR" lineID="A" trackID="3" km="9.650" />
  </Connector>
The electrical connection of track 1 and 2 at km 9+750.
  <Connector name="MW track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="MW" lineID="A" trackID="1" km="9.750" />
    <ConductorTo condName="MW" lineID="A" trackID="2" km="9.750" />
  </Connector>
  <Connector name="CW track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="CW" lineID="A" trackID="1" km="9.750" />
    <ConductorTo condName="CW" lineID="A" trackID="2" km="9.750" />
  </Connector>
  <Connector name="RL track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="RL" lineID="A" trackID="1" km="9.750" />
    <ConductorTo condName="RL" lineID="A" trackID="2" km="9.750" />
  </Connector>
  <Connector name="RR track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="RR" lineID="A" trackID="1" km="9.750" />
    <ConductorTo condName="RR" lineID="A" trackID="2" km="9.750" />
  </Connector>
```

```
<!-- Connections of rails and ocs at change over from track 1 to 2 line A. -->
<Connector name="MW track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="MW" lineID="A" trackID="1" km="10.250" />
  <ConductorTo condName="MW" lineID="A" trackID="2" km="10.250" />
</Connector>
<Connector name="CW track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="CW" lineID="A" trackID="1" km="10.250" />
  <ConductorTo condName="CW" lineID="A" trackID="2" km="10.250" />
</Connector>
<Connector name="RL track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="RL" lineID="A" trackID="1" km="10.250" />
  <ConductorTo condName="RL" lineID="A" trackID="2" km="10.250" />
</Connector>
<Connector name="RR track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="RR" lineID="A" trackID="1" km="10.250" />
  <ConductorTo condName="RR" lineID="A" trackID="2" km="10.250" />
</Connector>
<!-- Connections of rails and ocs at the crossing. -->
<Connector name="MW track 2-3, km 10+450" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="MW" lineID="A" trackID="2" km="10.450" />
  <ConductorTo condName="MW" lineID="A" trackID="3" km="10.450" />
</Connector>
<Connector name="CW track 2-3, km 10+450" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="CW" lineID="A" trackID="2" km="10.450" />
  <ConductorTo condName="CW" lineID="A" trackID="3" km="10.450" />
</Connector>
<Connector name="RL track 2-3, km 10+450" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="RL" lineID="A" trackID="2" km="10.450" />
  <ConductorTo condName="RL" lineID="A" trackID="3" km="10.450" />
</Connector>
<Connector name="RR track 2-3, km 10+450" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="RR" lineID="A" trackID="2" km="10.450" />
  <ConductorTo condName="RR" lineID="A" trackID="3" km="10.450" />
</Connector>
<!-- Connections of rails and ocs at change over from track 1 to 2 line B. -->
<Connector name="MW track 1-2, km 29+750" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="MW" lineID="B" trackID="1" km="29.750" />
  <ConductorTo condName="MW" lineID="B" trackID="2" km="29.750" />
</Connector>
<Connector name="CW track 1-2, km 29+750" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="CW" lineID="B" trackID="1" km="29.750" />
  <ConductorTo condName="CW" lineID="B" trackID="2" km="29.750" />
</Connector>
<Connector name="RL track 1-2, km 29+750" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="RL" lineID="B" trackID="1" km="29.750" />
  <ConductorTo condName="RL" lineID="B" trackID="2" km="29.750" />
</Connector>
<Connector name="RR track 1-2, km 29+750" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="RR" lineID="B" trackID="1" km="29.750" />
  <ConductorTo condName="RR" lineID="B" trackID="2" km="29.750" />
</Connector>
<!-- Connection between the lines. -->
<Connector name="MW track A 2 - B 1" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="MW" lineID="A" trackID="2" km="20" />
  <ConductorTo condName="MW" lineID="B" trackID="1" km="20" />
</Connector>
<Connector name="CW track A 2 - B 1" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="CW" lineID="A" trackID="2" km="20" />
  <ConductorTo condName="CW" lineID="B" trackID="1" km="20" />
</Connector>
<Connector name="RL track A 2 - B 1" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="RL" lineID="A" trackID="2" km="20" />
  <ConductorTo condName="RL" lineID="B" trackID="1" km="20" />
</Connector>
<Connector name="RR track A 2 - B 1" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="RR" lineID="A" trackID="2" km="20" />
  <ConductorTo condName="RR" lineID="B" trackID="1" km="20" />
</Connector>
<Connector name="E track 1, Line A - B" zReal_Ohm="0.000010" zImag_Ohm="0">
  <ConductorFrom condName="E" lineID="A" trackID="1" km="20" />
  <ConductorTo condName="E" lineID="B" trackID="1" km="20" />
```

```
  </Connector>
  <Connector name="MW track A 3 - B 2" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="MW" lineID="A" trackID="3" km="20" />
    <ConductorTo condName="MW" lineID="B" trackID="2" km="20" />
  </Connector>
  <Connector name="CW track A 3 - B 2" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="CW" lineID="A" trackID="3" km="20" />
    <ConductorTo condName="CW" lineID="B" trackID="2" km="20" />
  </Connector>
  <Connector name="RL track A 3 - B 2" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="RL" lineID="A" trackID="3" km="20" />
    <ConductorTo condName="RL" lineID="B" trackID="2" km="20" />
  </Connector>
  <Connector name="RR track A 3 - B 2" zReal_Ohm="0.000010" zImag_Ohm="0">
    <ConductorFrom condName="RR" lineID="A" trackID="3" km="20" />
    <ConductorTo condName="RR" lineID="B" trackID="2" km="20" />
  </Connector>
</Connectors>
```

Last but not least the configuration of the substations TSS_5, TSS_A_25 and TSS_B_25:

```
<Substations>
  <Substation name="TSS_5">
    <TwoWindingTransformer name="T1" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="27.5" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
      <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Switch name="TSS_5_T1_OCS" defaultState="close" />
      </OCSBB>
      <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Switch name="TSS_5_T1_Rails" defaultState="close" />
      </RailsBB>
    </TwoWindingTransformer>
    <Busbars>
      <OCSBB bbName="OCS_BB">
        <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="CW" lineID="A" trackID="1" km="5" />
        </Connector>
      </OCSBB>
      <RailsBB bbName="Rails_BB">
        <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="RR" lineID="A" trackID="1" km="5" />
        </Connector>
      </RailsBB>
    </Busbars>
  </Substation>

  <Substation name="TSS_A_25">
    <TwoWindingTransformer name="T1" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="27.5" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
      <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Switch name="TSS_A_25_T1_OCS" defaultState="close" />
      </OCSBB>
      <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Switch name="TSS_A_25_T1_Rails" defaultState="close" />
      </RailsBB>
    </TwoWindingTransformer>
    <Busbars>
      <OCSBB bbName="OCS_BB">
        <Connector name="TSS_A_25_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="CW" lineID="A" trackID="1" km="25" />
        </Connector>
      </OCSBB>
      <RailsBB bbName="Rails_BB">
        <Connector name="TSS_A_25_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="RR" lineID="A" trackID="1" km="25" />
        </Connector>
      </RailsBB>
    </Busbars>
```

```
  </Substation>

  <Substation name="TSS_B_25">
    <TwoWindingTransformer name="T1" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="27.5" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
      <OCSBB bbName="OCS_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Switch name="TSS_B_25_T1_OCS" defaultState="close" />
      </OCSBB>
      <RailsBB bbName="Rails_BB" z_real_Ohm="0.001" z_imag_Ohm="0">
        <Switch name="TSS_B_25_T1_Rails" defaultState="close" />
      </RailsBB>
    </TwoWindingTransformer>
    <Busbars>
      <OCSBB bbName="OCS_BB">
        <Connector name="TSS_B_25_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="CW" lineID="B" trackID="1" km="25" />
        </Connector>
      </OCSBB>
      <RailsBB bbName="Rails_BB">
        <Connector name="TSS_B_25_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
          <Position condName="RR" lineID="B" trackID="1" km="25" />
        </Connector>
      </RailsBB>
    </Busbars>
  </Substation>
</Substations>
```

As results only the engine data, substation currents and voltages shall be recorded.

```
<Network name="A-C" use="true" voltage_kV="25" frequency_Hz="50" recordVoltage="true"
recordCurrent="true">
  <Lines recordCurrent="false" recordVoltage="false">
...
  </Lines>
  <Connectors recordCurrent="false+sub" recordVoltage="false+sub">
...
  </Connectors>
  <Substations>
...
  </Substations>
  <Earth condName="E" lineID="A" trackID="1" km="0" />
</Network>
```

6.7.4.1.3 Simulation

To check the timetable and correct configuration of OpenTrack the first simulation run shall be without OpenPowerNet. Go in OpenTrack to `Info => OpenPowerNet Settings` and deselect Use OpenPowerNet.

The train graphs shall look like in Figure 125 and Figure 126.

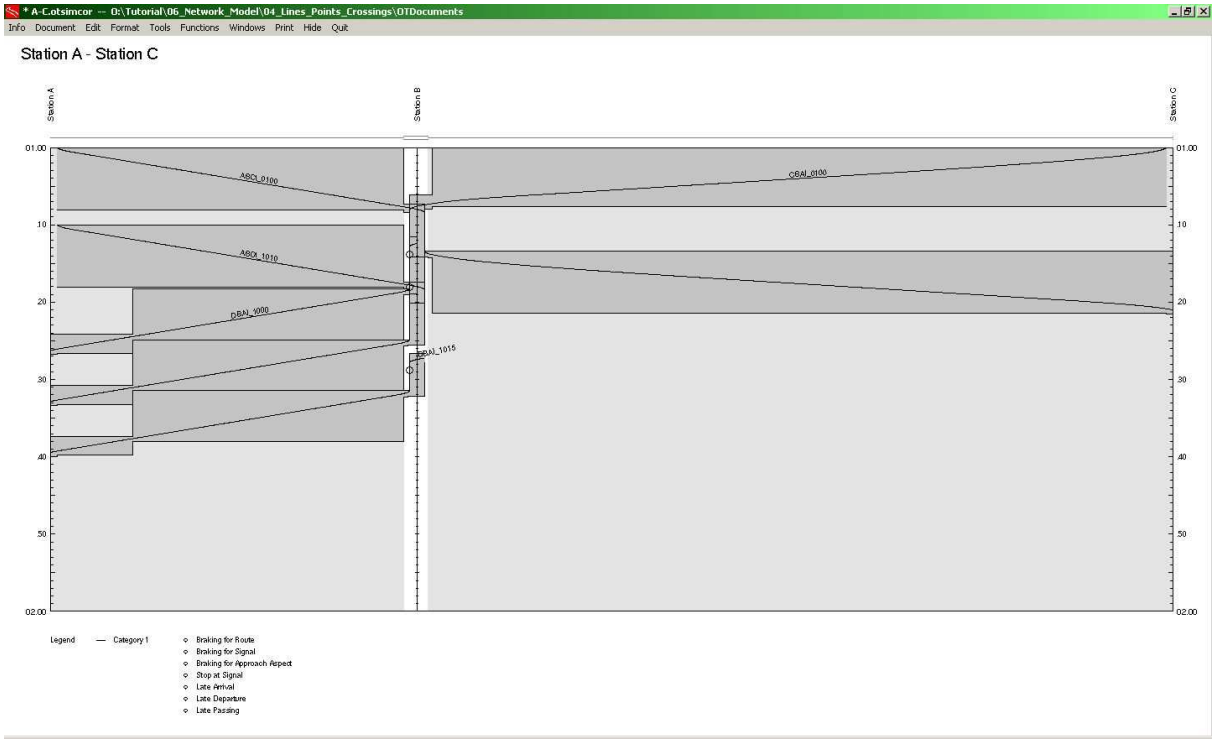


Figure 125 The train graph from station A to C.

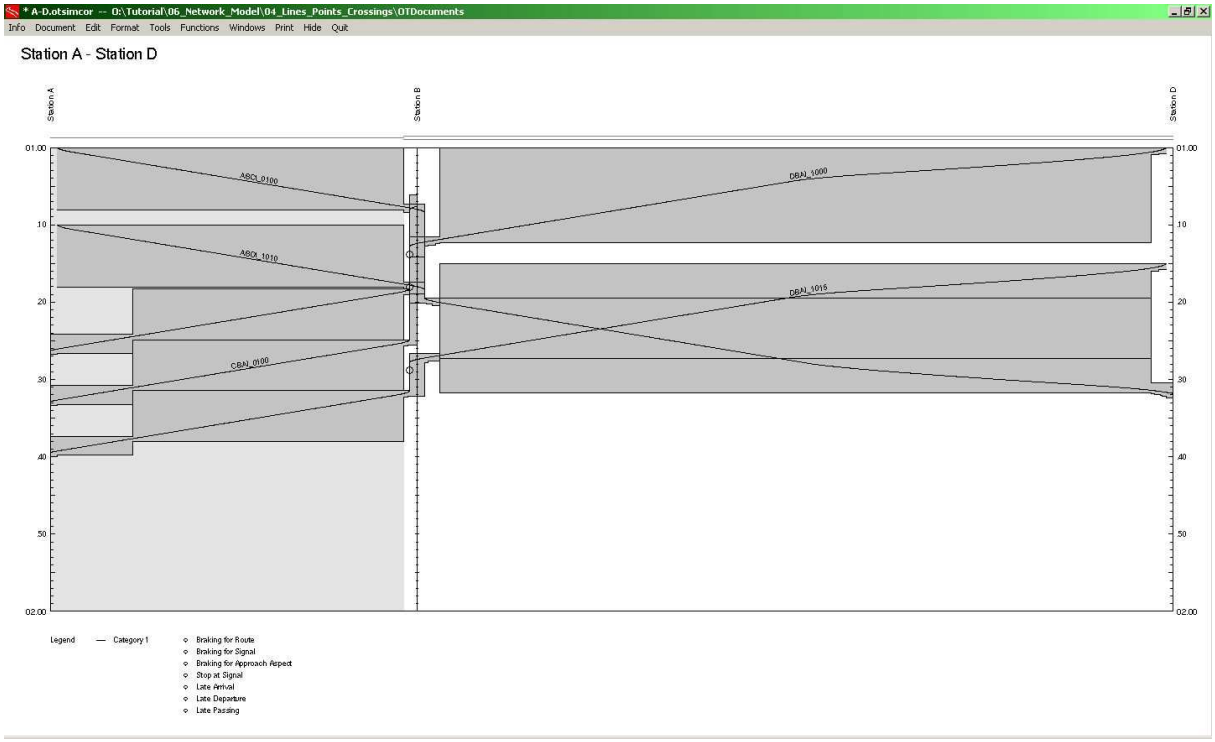


Figure 126 The train graph from station A to D.

After the correct timetable is confirmed we run the simulation.

6.7.4.1.4 Analysis

For analysis we will use Excel file Engine.xls.

	A	B	C	D	E	F	G	Q
1		1						
2	**Simulation**	001 10.09.2009 10:03:32 Tutorial lines, points, crossings 5 long trains, record all						
3		ABDI_1010						
4	**Train**	ABDI_1010						
5	**trainID**	**engineID**	**idx**	**time_s**	**lineID**	**trac**	**pos_km**	**Time**
1056	ABDI_1010	Engine1	0	5251	A	3	19,927	1:27:31
1057	ABDI_1010	Engine1	0	5252	A	3	19,948	1:27:32
1058	ABDI_1010	Engine1	0	5253	A	3	19,969	1:27:33
1059	ABDI_1010	Engine1	0	5254	A	3	19,989	1:27:34
1060	ABDI_1010	Engine1	0	5255	B	2	20,010	1:27:35
1061	ABDI_1010	Engine1	0	5256	B	2	20,031	1:27:36
1062	ABDI_1010	Engine1	0	5257	B	2	20,052	1:27:37
1063	ABDI_1010	Engine1	0	5258	B	2	20,073	1:27:38
1064	ABDI_1010	Engine1	0	5259	B	2	20,094	1:27:39

Figure 127 The positions of course ABDI_1010 with track change from line A to line B.

In Figure 127 we can see the change of course ABDI_1010 from line A to line B at 1:27:35. For each location there is a voltage and current value. That means the positions in OpenTrack and OpenPowerNet are the same. In case the position does not match than the voltage is 0 V.

The coupling of the conductors is only calculated for each line and no coupling between different lines. The difference for track 1 can be seen on the conductors of the left track in Figure 128 and Figure 129.

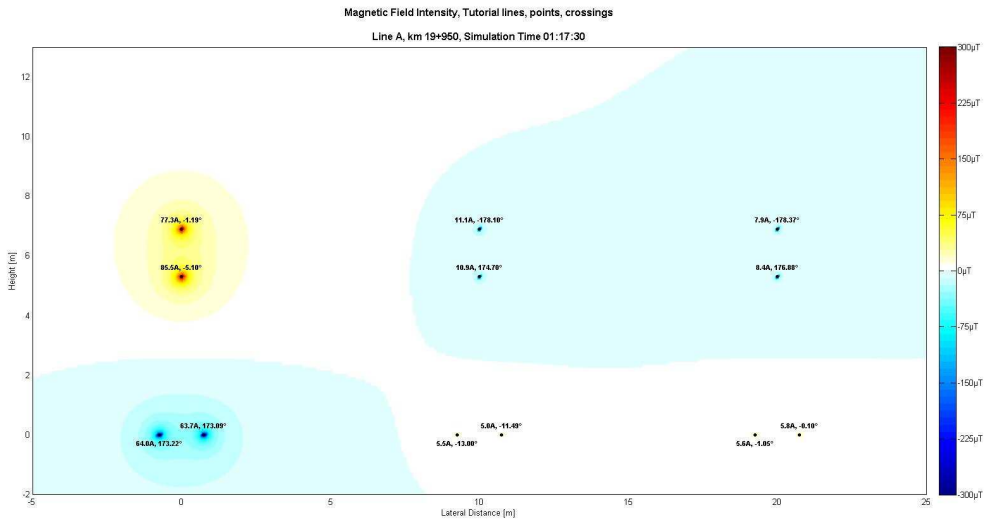


Figure 128 The magnetic field at line A, km 19+950 at 01:17:30.

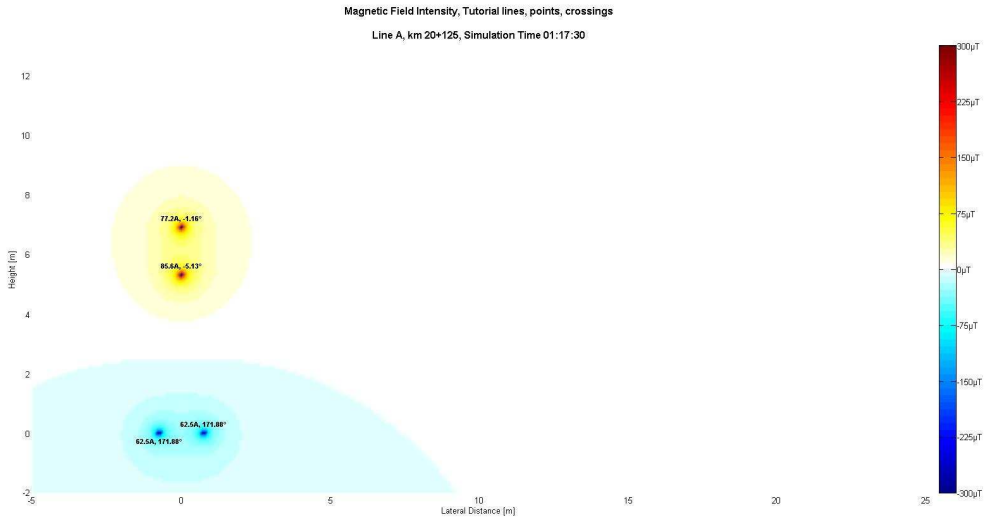


Figure 129 The magnetic field at line A km 20+125 at 01:17:30.

6.7.5 Turning loops tutorial

In this tutorial we will compare the effect of a wrong and a correct configuration for turning loops. Turning loops are typical for tram networks but also for other railway systems.

The wrong configuration will be wrong for OpenTrack and also wrong for OpenPowerNet. The simulation will still run but produce incorrect simulation results.

We will use 25 kV 50 Hz power supply system with one substation at km 5+000. The line shall be about 25km long and have 3 Station.

Two courses shall run as follow:

Course	Station A	Station B	Station C
ABCl_01	Start 01:00:00, track 1	Stop 60s, track 2	Terminate
CBAl_01	Terminate track 1 loop via track 2	Stop 60s, track 1	Start 01:00:00

Table 16 Timetable of courses in the loops totorial.

6.7.5.1 Configuration

6.7.5.1.1 OpenTrack

As the basis for the infrastructure we take the data from the AC tutorial. We need to add the loop and to change the chainage according to Figure 130 and Figure 131.

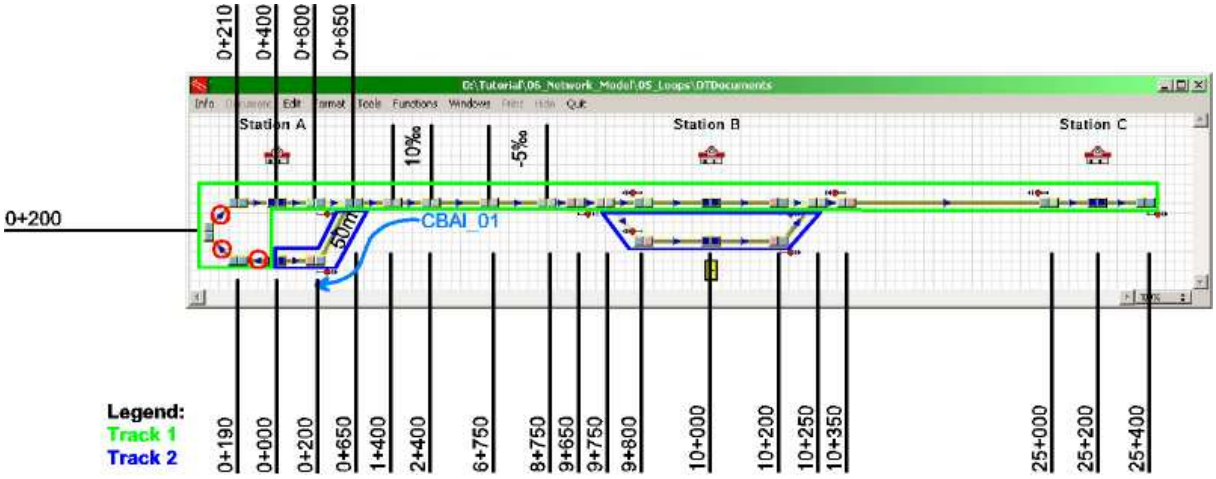


Figure 130 The wrong OpenTrack infrastructrue configuration of the loop tracks.

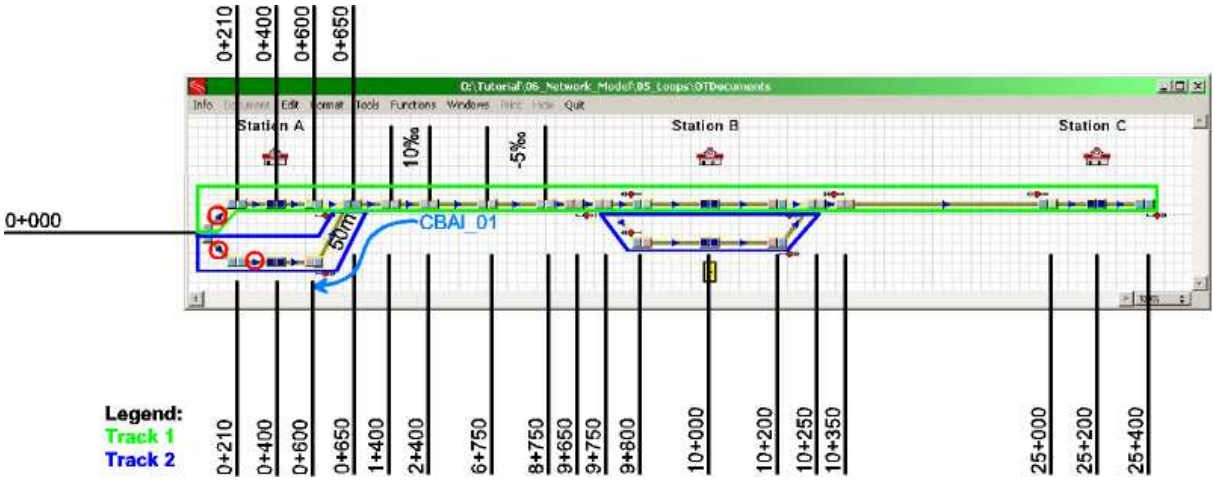


Figure 131 The correct OpenTrack infrastructrue configuration of the loop tracks.

Next after configuration of the infrastructure create new paths, routs, itineraries and courses according to Table 16.

6.7.5.1.2 OpenPowerNet

6.7.5.1.2.1 Engine-File

The engine file is the same as in the AC tutorial.

6.7.5.1.2.2 Project-File

According to the infrastructure defined in OpenTrack we need to configure the electrical network in OpenPowerNet.

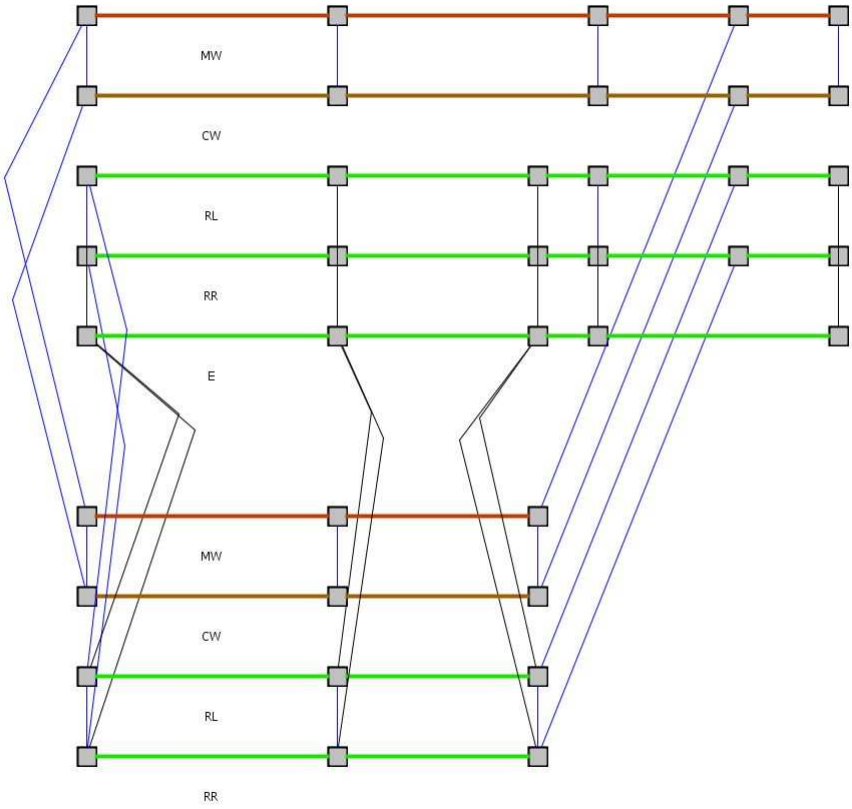


Figure 132 The wrong OpenPowerNet network configuration.

Lets first configure the wrong electrical network.

```
<?xml version="1.0" encoding="UTF-8"?>
<OpenPowerNet xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="http://www.dd.bahntechnik.de/opn/schemas/1.2.0/a2/OpenPowerNet.
xsd"
name="Network Tutorial - Loop"
comment="wrong"
maxIterations="1000"
maxFailedIterations="100"
odbcDsn="pscresults"
record2DB="true"
record2DB_Dump="true"
recordComputation2DB="false"
rstFile="D:\OPN_Projects\Tutorial\06_Network_Model\05_Loops\OPNData\Engine-File.xml"
simulationStart_s="3600">
  <ATM>
    <Vehicles>
      <Vehicle eddyCurrentBrake="false" engineID="Engine1">
        <Propulsion engine="electric" supply="AC 25kV 50Hz" brakeCurrentLimitation="none"
tractiveCurrentLimitation="none" useAuxPower="true" fourQuadrantChopperPhi="none"
regenerativeBrake="maxPower/maxEffort" tractiveEffort="maxPower/maxTractEffort">
          <MeanEfficiency />
        </Propulsion>
      </Vehicle>
    </Vehicles>
    <Options tolerance_A="0.1" maxIterations="1000" record2DB="true" />
  </ATM>
  <PSC>
    <Network name="A-C" use="true" voltage_kV="25" frequency_Hz="50" recordVoltage="true"
recordCurrent="true">
      <Lines>
        <Line name="A" maxSliceDistance_km="0.5">
```

The configuration of the conductors.

```
          <Conductors>
The conductors for track 1,
            <Conductor type="MessengerWire">
              <StartPosition condName="MW" trackID="1" km="0" />
              <ToProperty toPos_km="25.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0" y_m="6.9" />
            </Conductor>
            <Conductor type="ContactWire">
              <StartPosition condName="CW" trackID="1" km="0" />
              <ToProperty toPos_km="25.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="0" y_m="5.3" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RL" trackID="1" km="0" />
              <ToProperty toPos_km="25.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-0.75" y_m="0" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RR" trackID="1" km="0" />
              <ToProperty toPos_km="25.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0.75" y_m="0" />
            </Conductor>
for track2 in station A
            <Conductor type="MessengerWire">
              <StartPosition condName="MW" trackID="2" km="0" />
              <ToProperty toPos_km="0.450" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10" y_m="6.9" />
            </Conductor>
            <Conductor type="ContactWire">
              <StartPosition condName="CW" trackID="2" km="0" />
              <ToProperty toPos_km="0.450" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="10" y_m="5.3" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RL" trackID="2" km="0" />
              <ToProperty toPos_km="0.450" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="9.25" y_m="0" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RR" trackID="2" km="0" />
              <ToProperty toPos_km="0.450" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10.75" y_m="0" />
            </Conductor>
and for station B.
            <Conductor type="MessengerWire">
              <StartPosition condName="MW" trackID="2" km="9.750" />
              <ToProperty toPos_km="10.250" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10" y_m="6.9" />
            </Conductor>
            <Conductor type="ContactWire">
              <StartPosition condName="CW" trackID="2" km="9.750" />
              <ToProperty toPos_km="10.250" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="10" y_m="5.3" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RL" trackID="2" km="9.750" />
              <ToProperty toPos_km="10.250" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="9.25" y_m="0" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RR" trackID="2" km="9.750" />
              <ToProperty toPos_km="10.250" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10.75" y_m="0" />
            </Conductor>
            <Conductor type="Earth">
              <StartPosition condName="E" trackID="1" km="0" />
              <ToProperty toPos_km="25.4" equivalentRadius_mm="450000" r20_Ohm_km="0.0393"
temperature_GradCelsius="20" temperatureCoefficient="0" x_m="0" y_m="-450.0" />
            </Conductor>
          </Conductors>
The definition of connector slices. To have more detailed recoding data the slice distance in
```

the station A shall be only 50m. Outside the stations A and B the slice distance shall be 200m. And track 2 in station B slice distance 100m.

```
          <ConnectorSlices>
            <ConnectorSlice name="dropper, track 1, station A" firstPos_km="0" lastPos_km="1"
maxDistance_km="0.05">
              <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
                <ConductorFrom condName="MW" trackID="1" />
                <ConductorTo condName="CW" trackID="1" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="dropper, track 1, outside station A" firstPos_km="1.2"
lastPos_km="25.4" maxDistance_km="0.2">
              <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
                <ConductorFrom condName="MW" trackID="1" />
                <ConductorTo condName="CW" trackID="1" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="dropper, track 2, station A" firstPos_km="0"
lastPos_km="0.450" maxDistance_km="0.05">
              <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
                <ConductorFrom condName="MW" trackID="2" />
                <ConductorTo condName="CW" trackID="2" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="dropper, track 2, station B" firstPos_km="9.800"
lastPos_km="10.200" maxDistance_km="0.1">
              <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
                <ConductorFrom condName="MW" trackID="2" />
                <ConductorTo condName="CW" trackID="2" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="rail connector, track 1, station A" firstPos_km="0"
lastPos_km="1" maxDistance_km="0.05">
              <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
                <ConductorFrom condName="RL" trackID="1" />
                <ConductorTo condName="RR" trackID="1" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="rail connector, track 1, outside station A"
firstPos_km="1.2" lastPos_km="25.4" maxDistance_km="0.2">
              <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
                <ConductorFrom condName="RL" trackID="1" />
                <ConductorTo condName="RR" trackID="1" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="rail connector, track 2, station A" firstPos_km="0"
lastPos_km="0.450" maxDistance_km="0.05">
              <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
                <ConductorFrom condName="RL" trackID="2" />
                <ConductorTo condName="RR" trackID="2" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="rail connector, track 2, station B" firstPos_km="9.800"
lastPos_km="10.200" maxDistance_km="0.1">
              <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
                <ConductorFrom condName="RL" trackID="2" />
                <ConductorTo condName="RR" trackID="2" />
              </Connector>
            </ConnectorSlice>
          </ConnectorSlices>
```

The definition of the leakage.

```
          <Leakages>
```

Track 1

```
            <Leakage firstPos_km="0" lastPos_km="25.4" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RL" trackID="1" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
            <Leakage firstPos_km="0" lastPos_km="25.4" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RR" trackID="1" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
```

```
Track 2 in station A
            <Leakage firstPos_km="0" lastPos_km="0.450" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RL" trackID="2" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
            <Leakage firstPos_km="0" lastPos_km="0.450" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RR" trackID="2" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
Track 2 in station B.
            <Leakage firstPos_km="9.750" lastPos_km="10.250" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RL" trackID="2" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
            <Leakage firstPos_km="9.750" lastPos_km="10.250" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RR" trackID="2" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
          </Leakages>
        </Line>
      </Lines>
The connectors used to connect the conductors of the tracks.
      <Connectors>
        <Connector name="MW track 1 km 0+000 to track 2 km 0+000" zReal_Ohm="0.000010"
zImag_Ohm="0">
          <ConductorFrom condName="MW" lineID="A" trackID="1" km="0" />
          <ConductorTo condName="MW" lineID="A" trackID="2" km="0" />
        </Connector>
        <Connector name="CW track 1 km 0+000 to track 2 km 0+000" zReal_Ohm="0.000010"
zImag_Ohm="0">
          <ConductorFrom condName="CW" lineID="A" trackID="1" km="0" />
          <ConductorTo condName="CW" lineID="A" trackID="2" km="0" />
        </Connector>
        <Connector name="RL track 1 km 0+000 to track 2 km 0+000" zReal_Ohm="0.000010"
zImag_Ohm="0">
          <ConductorFrom condName="RL" lineID="A" trackID="1" km="0" />
          <ConductorTo condName="RL" lineID="A" trackID="2" km="0" />
        </Connector>
        <Connector name="RR track 1 km 0+000 to track 2 km 0+000" zReal_Ohm="0.000010"
zImag_Ohm="0">
          <ConductorFrom condName="RR" lineID="A" trackID="1" km="0" />
          <ConductorTo condName="RR" lineID="A" trackID="2" km="0" />
        </Connector>

        <Connector name="MW track 1 km 0+650 to track 2 km 0+450" zReal_Ohm="0.000010"
zImag_Ohm="0">
          <ConductorFrom condName="MW" lineID="A" trackID="1" km="0.650" />
          <ConductorTo condName="MW" lineID="A" trackID="2" km="0.450" />
        </Connector>
        <Connector name="CW track 1 km 0+650 to track 2 km 0+450" zReal_Ohm="0.000010"
zImag_Ohm="0">
          <ConductorFrom condName="CW" lineID="A" trackID="1" km="0.650" />
          <ConductorTo condName="CW" lineID="A" trackID="2" km="0.450" />
        </Connector>
        <Connector name="RL track 1 km 0+650 to track 2 km 0+450" zReal_Ohm="0.000010"
zImag_Ohm="0">
          <ConductorFrom condName="RL" lineID="A" trackID="1" km="0.650" />
          <ConductorTo condName="RL" lineID="A" trackID="2" km="0.450" />
        </Connector>
        <Connector name="RR track 1 km 0+650 to track 2 km 0+450" zReal_Ohm="0.000010"
zImag_Ohm="0">
          <ConductorFrom condName="RR" lineID="A" trackID="1" km="0.650" />
          <ConductorTo condName="RR" lineID="A" trackID="2" km="0.450" />
        </Connector>

        <Connector name="MW track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="MW" lineID="A" trackID="1" km="9.750" />
          <ConductorTo condName="MW" lineID="A" trackID="2" km="9.750" />
        </Connector>
        <Connector name="CW track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="CW" lineID="A" trackID="1" km="9.750" />
```

```
          <ConductorTo condName="CW" lineID="A" trackID="2" km="9.750" />
        </Connector>
        <Connector name="RL track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RL" lineID="A" trackID="1" km="9.750" />
          <ConductorTo condName="RL" lineID="A" trackID="2" km="9.750" />
        </Connector>
        <Connector name="RR track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RR" lineID="A" trackID="1" km="9.750" />
          <ConductorTo condName="RR" lineID="A" trackID="2" km="9.750" />
        </Connector>

        <Connector name="MW track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="MW" lineID="A" trackID="1" km="10.250" />
          <ConductorTo condName="MW" lineID="A" trackID="2" km="10.250" />
        </Connector>
        <Connector name="CW track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="CW" lineID="A" trackID="1" km="10.250" />
          <ConductorTo condName="CW" lineID="A" trackID="2" km="10.250" />
        </Connector>
        <Connector name="RL track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RL" lineID="A" trackID="1" km="10.250" />
          <ConductorTo condName="RL" lineID="A" trackID="2" km="10.250" />
        </Connector>
        <Connector name="RR track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RR" lineID="A" trackID="1" km="10.250" />
          <ConductorTo condName="RR" lineID="A" trackID="2" km="10.250" />
        </Connector>
      </Connectors>
The substation at km 5+000.
      <Substations>
        <Substation name="TSS_5">
          <TwoWindingTransformer name="T1" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="27.5" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
            <OCSBB bbName="OCS_BB_1" z_real_Ohm="0.001" z_imag_Ohm="0">
              <Switch name="TSS_5_T1_OCS" defaultState="close" />
            </OCSBB>
            <RailsBB bbName="Rails_BB_1" z_real_Ohm="0.001" z_imag_Ohm="0">
              <Switch name="TSS_5_T1_Rails" defaultState="close" />
            </RailsBB>
          </TwoWindingTransformer>
          <Busbars>
            <OCSBB bbName="OCS_BB_1">
              <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
                <Position condName="CW" lineID="A" trackID="1" km="5" />
                <Switch defaultState="close" name="TSS_5_OCS_Feeder_5.0" />
              </Connector>
            </OCSBB>
            <RailsBB bbName="Rails_BB_1">
              <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
                <Position condName="RL" lineID="A" trackID="1" km="5" />
                <Switch defaultState="close" name="TSS_5_Rails_Feeder_5.0" />
              </Connector>
            </RailsBB>
          </Busbars>
        </Substation>
      </Substations>
      <Earth condName="E" lineID="A" trackID="1" km="0" />
    </Network>
    <Options tolerance_grad="0.001" tolerance_V="0.1" tolerance_A="0.1" maxIncreaseCount="500"
discreteTrains="true" evenlyDistributedTractionReturnCurrent="true"
maxCurrentAngleIteration="100" />
  </PSC>
</OpenPowerNet>
```

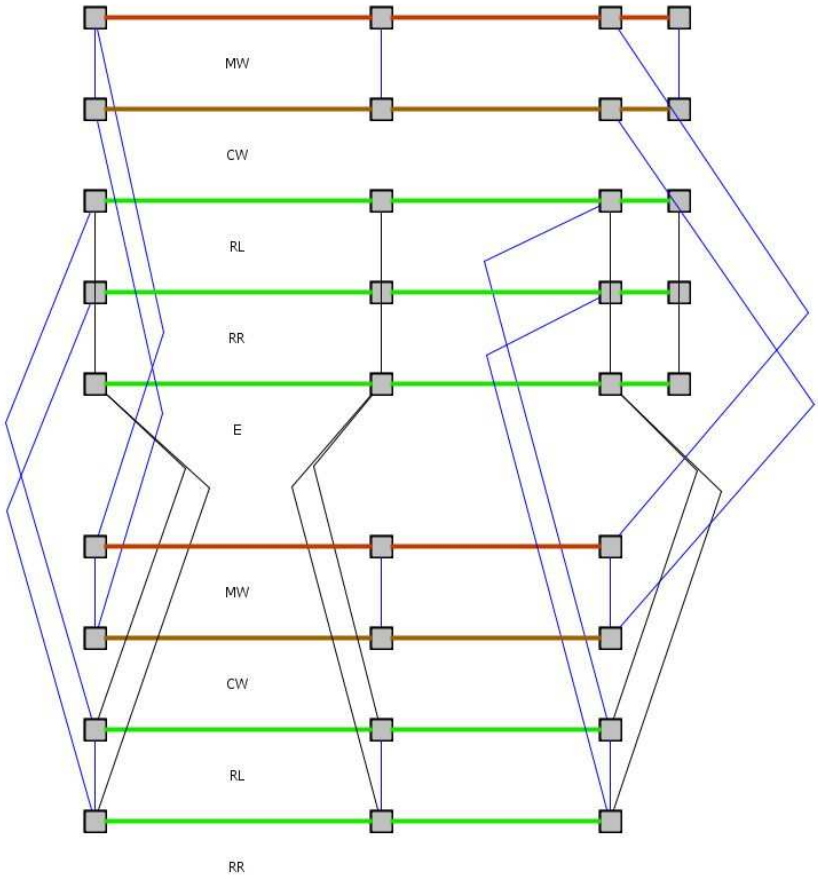


Figure 133 The correct OpenPowerNet network configuration.

```
<?xml version="1.0" encoding="UTF-8"?>
<OpenPowerNet
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="http://www.dd.bahntechnik.de/opn/schemas/1.2.0/a2/OpenPowerNet.
xsd"
name="Network Tutorial - Loop"
comment="correct"
maxIterations="1000"
maxFailedIterations="100"
odbcDsn="pscresults"
record2DB="true"
record2DB_Dump="true"
recordComputation2DB="false"
rstFile="D:\OPN_Projects\Tutorial\06_Network_Model\05_Loops\OPNData\Engine-File.xml"
simulationStart_s="3600">
  <ATM>
    <Vehicles>
      <Vehicle eddyCurrentBrake="false" engineID="Engine1">
        <Propulsion engine="electric" supply="AC 25kV 50Hz" brakeCurrentLimitation="none"
tractiveCurrentLimitation="none" useAuxPower="true" fourQuadrantChopperPhi="none"
regenerativeBrake="maxPower/maxEffort" tractiveEffort="maxPower/maxTractEffort">
          <MeanEfficiency />
        </Propulsion>
      </Vehicle>
    </Vehicles>
    <Options tolerance_A="0.1" maxIterations="1000" record2DB="true" />
  </ATM>
  <PSC>
    <Network name="A-C" use="true" voltage_kV="25" frequency_Hz="50" recordVoltage="true"
recordCurrent="true">
```

```
      <Lines>
        <Line name="A" maxSliceDistance_km="0.5">
The configuration of the conductors.
          <Conductors>
The conductors for track 1.
            <Conductor type="MessengerWire">
              <StartPosition condName="MW" trackID="1" km="0.2" />
              <ToProperty toPos_km="25.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0" y_m="6.9" />
            </Conductor>
            <Conductor type="ContactWire">
              <StartPosition condName="CW" trackID="1" km="0.2" />
              <ToProperty toPos_km="25.4" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="0" y_m="5.3" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RL" trackID="1" km="0.2" />
              <ToProperty toPos_km="25.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="-0.75" y_m="0" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RR" trackID="1" km="0.2" />
              <ToProperty toPos_km="25.4" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="0.75" y_m="0" />
            </Conductor>
The conductors for track 2 in station A.
            <Conductor type="MessengerWire">
              <StartPosition condName="MW" trackID="2" km="0.2" />
              <ToProperty toPos_km="0.650" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10" y_m="6.9" />
            </Conductor>
            <Conductor type="ContactWire">
              <StartPosition condName="CW" trackID="2" km="0.2" />
              <ToProperty toPos_km="0.650" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="10" y_m="5.3" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RL" trackID="2" km="0.2" />
              <ToProperty toPos_km="0.650" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="9.25" y_m="0" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RR" trackID="2" km="0.2" />
              <ToProperty toPos_km="0.650" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10.75" y_m="0" />
            </Conductor>
The conductors for track 2 in station B.
            <Conductor type="MessengerWire">
              <StartPosition condName="MW" trackID="2" km="9.750" />
              <ToProperty toPos_km="10.250" equivalentRadius_mm="3.45" r20_Ohm_km="0.2311"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10" y_m="6.9" />
            </Conductor>
            <Conductor type="ContactWire">
              <StartPosition condName="CW" trackID="2" km="9.750" />
              <ToProperty toPos_km="10.250" equivalentRadius_mm="3.45" r20_Ohm_km="0.1852"
temperature_GradCelsius="20" temperatureCoefficient="0.00385" x_m="10" y_m="5.3" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RL" trackID="2" km="9.750" />
              <ToProperty toPos_km="10.250" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="9.25" y_m="0" />
            </Conductor>
            <Conductor type="Rail">
              <StartPosition condName="RR" trackID="2" km="9.750" />
              <ToProperty toPos_km="10.250" equivalentRadius_mm="38.52" r20_Ohm_km="0.0306"
temperature_GradCelsius="20" temperatureCoefficient="0.004" x_m="10.75" y_m="0" />
            </Conductor>
            <Conductor type="Earth">
              <StartPosition condName="E" trackID="1" km="0.2" />
              <ToProperty toPos_km="25.4" equivalentRadius_mm="450000" r20_Ohm_km="0.0393"
temperature_GradCelsius="20" temperatureCoefficient="0" x_m="0" y_m="-450.0" />
```

```
            </Conductor>
          </Conductors>
The definition of connector slices. To have more detailed recoding data the slice distance in
the station A shall be only 50m. Outside the stations A and B the slice distance shall be
200m. And track 2 in station B slice distance 100m.
          <ConnectorSlices>
            <ConnectorSlice name="dropper, track 1, station A" firstPos_km="0.2"
lastPos_km="1" maxDistance_km="0.05">
              <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
                <ConductorFrom condName="MW" trackID="1" />
                <ConductorTo condName="CW" trackID="1" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="dropper, track 1, outside station A" firstPos_km="1.2"
lastPos_km="25.4" maxDistance_km="0.2">
              <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
                <ConductorFrom condName="MW" trackID="1" />
                <ConductorTo condName="CW" trackID="1" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="dropper, track 2, station A" firstPos_km="0.2"
lastPos_km="0.650" maxDistance_km="0.05">
              <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
                <ConductorFrom condName="MW" trackID="2" />
                <ConductorTo condName="CW" trackID="2" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="dropper, track 2, station B" firstPos_km="9.800"
lastPos_km="10.200" maxDistance_km="0.1">
              <Connector zReal_Ohm="0.000073" zImag_Ohm="0">
                <ConductorFrom condName="MW" trackID="2" />
                <ConductorTo condName="CW" trackID="2" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="rail connector, track 1, station A" firstPos_km="0.2"
lastPos_km="1" maxDistance_km="0.05">
              <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
                <ConductorFrom condName="RL" trackID="1" />
                <ConductorTo condName="RR" trackID="1" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="rail connector, track 1, outside station A"
firstPos_km="1.2" lastPos_km="25.4" maxDistance_km="0.2">
              <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
                <ConductorFrom condName="RL" trackID="1" />
                <ConductorTo condName="RR" trackID="1" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="rail connector, track 2, station A" firstPos_km="0.2"
lastPos_km="0.650" maxDistance_km="0.05">
              <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
                <ConductorFrom condName="RL" trackID="2" />
                <ConductorTo condName="RR" trackID="2" />
              </Connector>
            </ConnectorSlice>
            <ConnectorSlice name="rail connector, track 2, station B" firstPos_km="9.800"
lastPos_km="10.200" maxDistance_km="0.1">
              <Connector zReal_Ohm="0.00001" zImag_Ohm="0">
                <ConductorFrom condName="RL" trackID="2" />
                <ConductorTo condName="RR" trackID="2" />
              </Connector>
            </ConnectorSlice>
          </ConnectorSlices>
The configuration of the leakages.
          <Leakages>
Leakage of track 1 in station A.
            <Leakage firstPos_km="0.2" lastPos_km="25.4" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RL" trackID="1" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
            <Leakage firstPos_km="0.2" lastPos_km="25.4" yReal_S_km="0.1" yImag_S_km="0">
```

```
              <ConductorFrom condName="RR" trackID="1" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
Leakage of track 2 in station A.
            <Leakage firstPos_km="0.2" lastPos_km="0.650" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RL" trackID="2" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
            <Leakage firstPos_km="0.2" lastPos_km="0.650" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RR" trackID="2" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
Leakage of track 2 in station B.
            <Leakage firstPos_km="9.750" lastPos_km="10.250" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RL" trackID="2" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
            <Leakage firstPos_km="9.750" lastPos_km="10.250" yReal_S_km="0.1" yImag_S_km="0">
              <ConductorFrom condName="RR" trackID="2" />
              <ConductorTo condName="E" trackID="1" />
            </Leakage>
          </Leakages>
        </Line>
      </Lines>
The connectors used to connect the conductors of the tracks.
      <Connectors>
        <Connector name="MW track 1-2, km 0+200" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="MW" lineID="A" trackID="1" km="0.200" />
          <ConductorTo condName="MW" lineID="A" trackID="2" km="0.200" />
        </Connector>
        <Connector name="CW track 1-2, km 0+200" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="CW" lineID="A" trackID="1" km="0.200" />
          <ConductorTo condName="CW" lineID="A" trackID="2" km="0.200" />
        </Connector>
        <Connector name="RL track 1-2, km 0+200" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RL" lineID="A" trackID="1" km="0.200" />
          <ConductorTo condName="RL" lineID="A" trackID="2" km="0.200" />
        </Connector>
        <Connector name="RR track 1-2, km 0+200" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RR" lineID="A" trackID="1" km="0.200" />
          <ConductorTo condName="RR" lineID="A" trackID="2" km="0.200" />
        </Connector>

        <Connector name="MW track 1-2, km 0+650" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="MW" lineID="A" trackID="1" km="0.650" />
          <ConductorTo condName="MW" lineID="A" trackID="2" km="0.650" />
        </Connector>
        <Connector name="CW track 1-2, km 0+650" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="CW" lineID="A" trackID="1" km="0.650" />
          <ConductorTo condName="CW" lineID="A" trackID="2" km="0.650" />
        </Connector>
        <Connector name="RL track 1-2, km 0+650" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RL" lineID="A" trackID="1" km="0.650" />
          <ConductorTo condName="RL" lineID="A" trackID="2" km="0.650" />
        </Connector>
        <Connector name="RR track 1-2, km 0+650" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RR" lineID="A" trackID="1" km="0.650" />
          <ConductorTo condName="RR" lineID="A" trackID="2" km="0.650" />
        </Connector>

        <Connector name="MW track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="MW" lineID="A" trackID="1" km="9.750" />
          <ConductorTo condName="MW" lineID="A" trackID="2" km="9.750" />
        </Connector>
        <Connector name="CW track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="CW" lineID="A" trackID="1" km="9.750" />
          <ConductorTo condName="CW" lineID="A" trackID="2" km="9.750" />
        </Connector>
        <Connector name="RL track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RL" lineID="A" trackID="1" km="9.750" />
          <ConductorTo condName="RL" lineID="A" trackID="2" km="9.750" />
```

```
        </Connector>
        <Connector name="RR track 1-2, km 9+750" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RR" lineID="A" trackID="1" km="9.750" />
          <ConductorTo condName="RR" lineID="A" trackID="2" km="9.750" />
        </Connector>

        <Connector name="MW track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="MW" lineID="A" trackID="1" km="10.250" />
          <ConductorTo condName="MW" lineID="A" trackID="2" km="10.250" />
        </Connector>
        <Connector name="CW track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="CW" lineID="A" trackID="1" km="10.250" />
          <ConductorTo condName="CW" lineID="A" trackID="2" km="10.250" />
        </Connector>
        <Connector name="RL track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RL" lineID="A" trackID="1" km="10.250" />
          <ConductorTo condName="RL" lineID="A" trackID="2" km="10.250" />
        </Connector>
        <Connector name="RR track 1-2, km 10+250" zReal_Ohm="0.000010" zImag_Ohm="0">
          <ConductorFrom condName="RR" lineID="A" trackID="1" km="10.250" />
          <ConductorTo condName="RR" lineID="A" trackID="2" km="10.250" />
        </Connector>
      </Connectors>
      <Substations>
The substation at km 5+000.
        <Substation name="TSS_5">
          <TwoWindingTransformer name="T1" nomPower_MVA="10" nomPrimaryVoltage_kV="115"
nomSecondaryVoltage_kV="27.5" noLoadLosses_kW="6.5" loadLosses_kW="230"
relativeShortCircuitVoltage_percent="10.7" noLoadCurrent_A="0.06">
            <OCSBB bbName="OCS_BB_1" z_real_Ohm="0.001" z_imag_Ohm="0">
              <Switch name="TSS_5_T1_OCS" defaultState="close" />
            </OCSBB>
            <RailsBB bbName="Rails_BB_1" z_real_Ohm="0.001" z_imag_Ohm="0">
              <Switch name="TSS_5_T1_Rails" defaultState="close" />
            </RailsBB>
          </TwoWindingTransformer>
          <Busbars>
            <OCSBB bbName="OCS_BB_1">
              <Connector name="TSS_5_OCS_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
                <Position condName="CW" lineID="A" trackID="1" km="5" />
                <Switch defaultState="close" name="TSS_5_OCS_Feeder_5.0" />
              </Connector>
            </OCSBB>
            <RailsBB bbName="Rails_BB_1">
              <Connector name="TSS_5_Rails_Feeder" z_real_Ohm="0.001" z_imag_Ohm="0">
                <Position condName="RL" lineID="A" trackID="1" km="5" />
                <Switch defaultState="close" name="TSS_5_Rails_Feeder_5.0" />
              </Connector>
            </RailsBB>
          </Busbars>
        </Substation>
      </Substations>
      <Earth condName="E" lineID="A" trackID="1" km="0.2" /> Note the beginning of the earth
conductor at km 0+200!
    </Network>
    <Options tolerance_grad="0.001" tolerance_V="0.1" tolerance_A="0.1" maxIncreaseCount="500"
discreteTrains="true" evenlyDistributedTractionReturnCurrent="true"
maxCurrentAngleIteration="100" />
  </PSC>
</OpenPowerNet>
```

6.7.5.1.3 Simulation

Run both simulations one after the other. Make sure that you upload the dump files after the first simulation.

6.7.5.1.4 Analysis

For analysis we will use the Excel files Engine.xls and CurrentTotal.xls as well as the analysis tool.

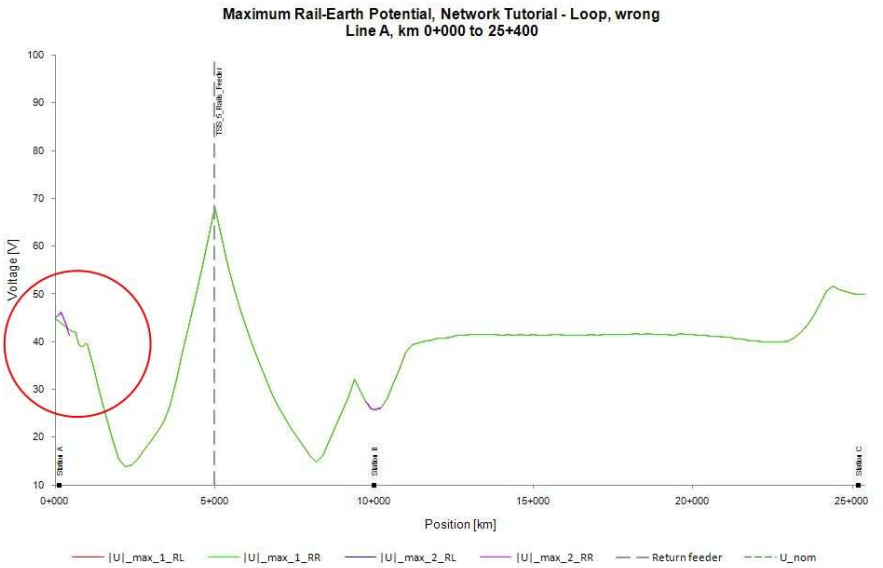


Figure 134 The maximum rail-earth potential of the simulation with the wrong network configuration.

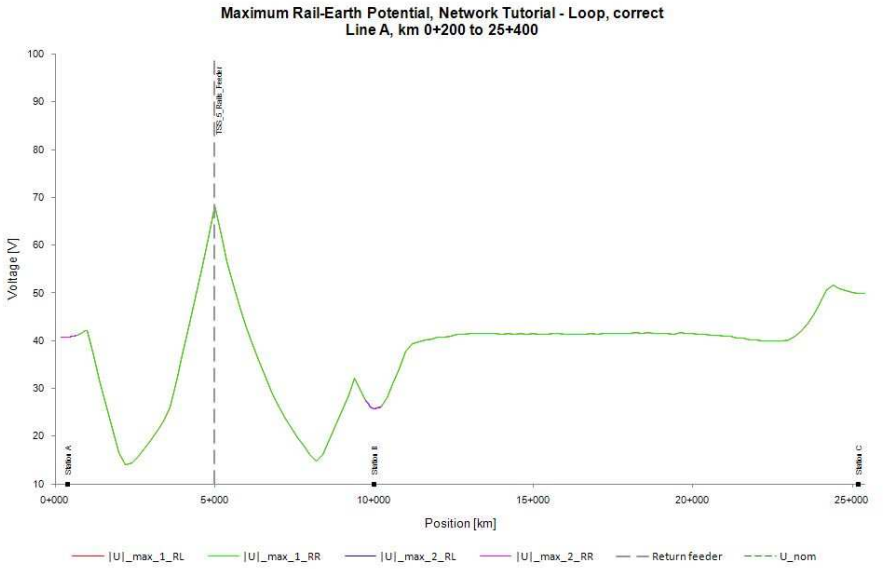


Figure 135 The maximum rail-earth potential of the simulation with the correct network configuration.

Figure 134 and Figure 135 show the maximum rail-earth potential for both simulations. For the wrong simulation the rail-earth potential in station A is much higher than for the correct simulation.

Figure 136 shows the values of the current sum of all conductors per section for the total simulation time. Between km 0+405 and km 0+650 the value is not close to 0 A, this means there is a connector parallel to conductors. And this is against the model constraints listed in chapter 4.2.1.

Total _real	Total_imag	from pos_km	to pos_km	Conductor center pos [km]
0,651	0,617	0,000	0,050	0+025
0,586	0,565	0,050	0,100	0+075
0,646	0,592	0,100	0,150	0+125
0,615	0,602	0,150	0,200	0+175
0,604	0,560	0,200	0,250	0+225
0,670	0,642	0,250	0,300	0+275
0,600	0,611	0,300	0,350	0+325
0,630	0,544	0,350	0,400	0+375
0,664	0,633	0,400	0,450	0+425
2261,202	4343,398	0,450	0,500	0+475
2261,265	4343,481	0,500	0,550	0+525
2261,198	4343,462	0,550	0,600	0+575
2261,273	4343,347	0,600	0,650	0+625
0,538	0,518	0,650	0,700	0+675
0,524	0,514	0,700	0,750	0+725

Figure 136 The sum of sum currents per section over the total simulation time of the wrong simulation.

trainID	lineID	trackID	pos_km	current_real_A	current_i	voltage	voltage	effort_requested	effort_achieved	speed	Time
CBAI_01	A	1	0,906	36,153	0,000	27459,0	-143,7	20,5	20,5	74,88	1:15:37
CBAI_01	A	1	0,885	36,162	0,000	27451,6	-177,0	20,5	20,5	74,88	1:15:38
CBAI_01	A	1	0,864	36,172	0,000	27443,8	-211,3	20,5	20,5	74,88	1:15:39
CBAI_01	A	1	0,843	36,182	0,000	27436,1	-244,9	20,5	20,5	74,88	1:15:40
CBAI_01	A	1	0,822	36,193	0,000	27427,8	-279,3	20,5	20,5	74,88	1:15:41
CBAI_01	A	1	0,802	36,203	0,000	27419,7	-313,0	20,5	20,5	74,88	1:15:42
CBAI_01	A	1	0,781	36,213	0,000	27411,4	-346,9	20,5	20,5	74,88	1:15:43
CBAI_01	A	1	0,760	36,224	0,000	27402,6	-381,5	20,5	20,5	74,88	1:15:44
CBAI_01	A	1	0,739	36,235	0,000	27393,9	-415,5	20,5	20,5	74,88	1:15:45
CBAI_01	A	1	0,718	36,247	0,000	27384,7	-450,2	20,5	20,5	74,88	1:15:46
CBAI_01	A	1	0,697	36,258	0,000	27375,5	-484,3	20,5	20,5	74,88	1:15:47
CBAI_01	A	1	0,677	36,215	0,000	27410,2	-350,7	20,5	20,5	74,88	1:15:48
CBAI_01	A	1	0,656	36,215	0,000	27409,9	-351,4	20,5	20,5	74,88	1:15:49
CBAI_01	A	2	0,635	0,000	0,000	0,0	0,0	20,5	0,0	74,88	1:15:50
CBAI_01	A	2	0,193	194,978	0,000	26901,7	-1878,0	206,0	206,0	74,52	1:15:52
CBAI_01	A	2	0,173	36,217	0,000	27408,7	-355,0	20,5	20,5	74,88	1:15:53
CBAI_01	A	2	0,152	36,217	0,000	27408,7	-355,0	20,5	20,5	74,88	1:15:54
CBAI_01	A	2	0,131	36,217	0,000	27408,7	-355,0	20,5	20,5	74,88	1:15:55
CBAI_01	A	2	0,110	36,217	0,000	27408,6	-355,4	20,5	20,5	74,88	1:15:56
CBAI_01	A	2	0,089	36,217	0,000	27408,6	-355,4	20,5	20,5	74,88	1:15:57
CBAI_01	A	2	0,068	36,217	0,000	27408,5	-355,6	20,5	20,5	74,88	1:15:58

Figure 137 The simulation values to course CBAI_01 for the wrong simulation with missing data at 1:15:51.

In Figure 137 the values of course CBAI_01 are incomplete because the configuration of OpenTrack infrastructure is not correct respective does not match with the OpenPowerNet positions. The course CBAI_01 is approaching station A and change from track 1 to track 2 at km 0+650. OpenTrack determine the chainage always counting the distance from the last vertex. Counting + or – depends on the direction of the edge and the direction of the course. In our case the course pass vertex at km 0+650 and move to track 2. So the actual position is the vertex at km 0+650 minus 15 m, this is km 0+635 at track 2. The solution may be to add an additional vertex at the end of track 2 (km 0+450) with an edge length of 0 m to vertex km 0+650 at track 1. This is a workaround for this problem but the electrical configuration is still wrong.

This tutorial shows the very important constraint to have always a current sum of 0 A for all conductors in the same section. This means it is not allowed to add connectors parallel to conductors.

7 FAQ

7.1 What needs to be considered in OpenTrack to use OpenPowerNet?

During creation of the OpenTrack project the following constraints need to be considered:

- Direction of edges has to be continuous,

- Chainage has to be positive,
- Set km point of each double vertex,
- Set length of all edges,
- Set line ID of all edges,
- Set track ID of all edges,
- Specify power supply areas.

It is helpful to prevent unnecessary changes in chainage or line and track IDs during creation of the OpenTrack project to simplify the electrical network model.

If there are engines with same OpenTrack input data but different electrical parameters for the same catenary system, these engines have to be handled separately. A multi-system traction unit can be handled as a single engine though.

Phase insulation gaps or voltage-free areas should get “power off” and “power on” signals in OpenTrack.

Note: Check `Use Curve Resistance` in OpenTrack preferences to respect each curve in your track layout. If this option is not set OpenTrack uses a mean radius to calculate driving resistance.

7.2 How to deal with broken chainage?

In general it is advised to avoid broken chainage!

There are two different kinds of broken chainage, a positive and a negative, see Figure 138.

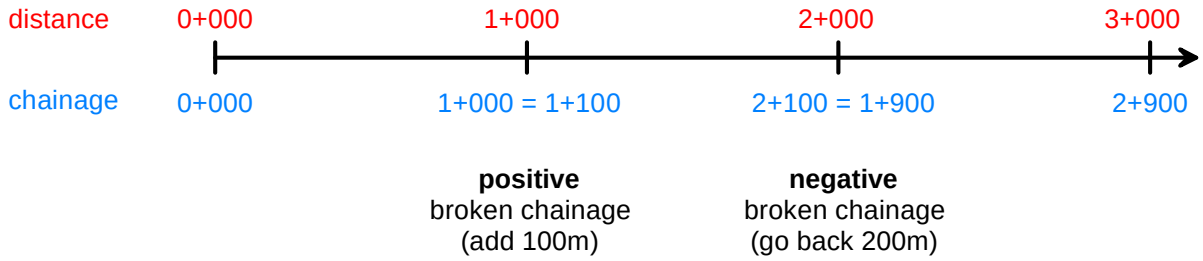


Figure 138 The two kinds of broken chainage as example.

Each kind has to be handled different in OpenTrack and OpenPowerNet. See Figure 139 for the PSC Viewer Diagram of the solution in OpenPowerNet. The detailed description follows in the next chapters.

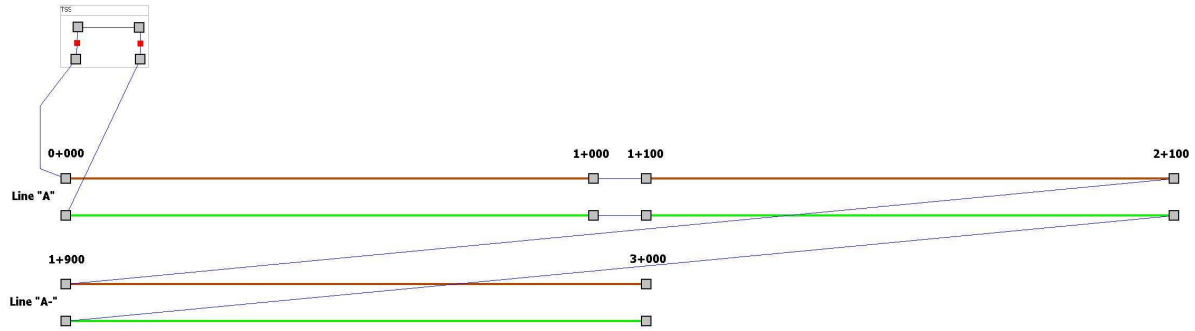


Figure 139 The positive and negative broken chainage modelled in OpenPowerNet.

7.2.1 Positive broken chainage

Positive is easier to model than the other one. According to the example in Figure 138 we just need in OpenTrack to set km 1+000 at one side of the double vertex and km 1+100 at the other side.

In OpenPowerNet we define conductors ending at km 1+000 and start new conductors at km 1+100. Then we have to connect the conductors with each other using low resistance connectors, see the upper conductors in Figure 139. The Project-File XML snippet shows the conductor and connector configuration of the example.

```
<Line name="A" maxSliceDistance_km="0.1" recordCurrent="true" recordVoltage="true">
  <Conductors>
    <Conductor type="ContactWire">
      <StartPosition km="0" trackID="up" condName="CW" />
      <ToProperty x_m="0" y_m="5.3" r20_Ohm_km="0.2138" equivalentRadius_mm="4.4"
toPos_km="1.000" temperatureCoefficient="0.00381" temperature_GradCelsius="40" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition km="0" trackID="up" condName="R" />
      <ToProperty x_m="0" y_m="0" r20_Ohm_km="0.0164" equivalentRadius_mm="38.52"
toPos_km="1.000" temperatureCoefficient="0.0047" temperature_GradCelsius="40" />
    </Conductor>
    <Conductor type="ContactWire">
      <StartPosition km="1.100" trackID="up" condName="CW" />
      <ToProperty x_m="5" y_m="5.3" r20_Ohm_km="0.2138" equivalentRadius_mm="4.4"
toPos_km="2.100" temperatureCoefficient="0.00381" temperature_GradCelsius="40" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition km="1.100" trackID="up" condName="R" />
      <ToProperty x_m="5" y_m="0" r20_Ohm_km="0.0164" equivalentRadius_mm="38.52"
toPos_km="2.100" temperatureCoefficient="0.0047" temperature_GradCelsius="40" />
    </Conductor>
  </Conductors>
</Line>
<Connectors>
  <Connector zReal_Ohm="0.0001" zImag_Ohm="0.0">
    <ConductorFrom km="1.000" trackID="up" condName="CW" lineID="A" />
    <ConductorTo km="1.100" trackID="up" condName="CW" lineID="A" />
  </Connector>
  <Connector zReal_Ohm="0.0001" zImag_Ohm="0.0">
    <ConductorFrom km="1.000" trackID="up" condName="R" lineID="A" />
    <ConductorTo km="1.100" trackID="up" condName="R" lineID="A" />
  </Connector>
</Connectors>
```

7.2.2 Negative broken chainage

The model in OpenTrack is the same as for positive broken chainage. Set km 2+100 at one side of the double vertex and km 1+900 at the other and define a new line name for the following edges. Always take care of the edge direction!

In OpenPowerNet we need to have two lines. In this example the line “A” from km 0+000 to 2+100 and line “A-“ from km1+900 to 3+000. Then we have to connect the conductors with each other using low resistance connectors, see Figure 139. The Project-File XML snippet shows the conductor and connector configuration of the example.

```
<Line name="A" maxSliceDistance_km="0.1" recordCurrent="true" recordVoltage="true">
  <Conductors>
    <Conductor type="ContactWire">
      <StartPosition km="1.100" trackID="up" condName="CW" />
      <ToProperty x_m="5" y_m="5.3" r20_Ohm_km="0.2138" equivalentRadius_mm="4.4"
toPos_km="2.100" temperatureCoefficient="0.00381" temperature_GradCelsius="40" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition km="1.100" trackID="up" condName="R" />
      <ToProperty x_m="5" y_m="0" r20_Ohm_km="0.0164" equivalentRadius_mm="38.52"
toPos_km="2.100" temperatureCoefficient="0.0047" temperature_GradCelsius="40" />
    </Conductor>
  </Conductors>
</Line>
<Line name="A-" maxSliceDistance_km="0.1" recordCurrent="true" recordVoltage="true">
  <Conductors>
    <Conductor type="ContactWire">
      <StartPosition km="1.900" trackID="up" condName="CW" />
      <ToProperty x_m="0" y_m="5.3" r20_Ohm_km="0.2138" equivalentRadius_mm="4.4"
toPos_km="3.000" temperatureCoefficient="0.00381" temperature_GradCelsius="40" />
    </Conductor>
    <Conductor type="Rail">
      <StartPosition km="1.900" trackID="up" condName="R" />
      <ToProperty x_m="0" y_m="0" r20_Ohm_km="0.0164" equivalentRadius_mm="38.52"
toPos_km="3.000" temperatureCoefficient="0.0047" temperature_GradCelsius="40" />
    </Conductor>
  </Conductors>
</Line>
<Connectors>
  <Connector zReal_Ohm="0.0001" zImag_Ohm="0.0">
    <ConductorFrom km="2.100" trackID="up" condName="CW" lineID="A" />
    <ConductorTo km="1.900" trackID="up" condName="CW" lineID="A-" />
  </Connector>
  <Connector zReal_Ohm="0.0001" zImag_Ohm="0.0">
    <ConductorFrom km="2.100" trackID="up" condName="R" lineID="A" />
    <ConductorTo km="1.900" trackID="up" condName="R" lineID="A-" />
  </Connector>
</Connectors>
```

7.3 How to organise the files and folders?

See chapter 6.1.

7.4 How to calculate the equivalent radius?

First determine the cross section A of the given conductor and convert this value to radius r of a circular cross section with same area A_{circle}, see the formula below.

$$A = A_{circle} = \pi \cdot r^2$$

$$r = \left| \sqrt{\frac{A}{\pi}} \right|$$

Second the radius r of the circular cross section needs to be multiplied with factor a to get the equivalent radius r_{eq}.

$$r_{eq} = a \cdot r$$

conductor type	a
solid cylindrical	0.779
Al and Cu cables, 7 cores, 10-50mm²	0.726
Al and Cu cables, 19 cores, 70-120mm²	0.758
Al and Cu cables, 37 cores, 150-185mm²	0.768
Al and Cu cables, 61 cores, 240-500mm²	0.772
Al and Cu cables, 91 cores, 625-1000mm²	0.774
1 layer Al/Fe cables, 16/2.5 – 300/50mm²	0.55
1 layer Al/Fe cables, 44/32 – 120/70mm²	0.7
2 layers Al/Fe cables, 26 cores, 120/20 – 300/50mm²	0.809
2 layers Al/Fe cables, 30 cores, 125/30 – 210/50mm²	0.826
3 layers Al/Fe cables, 54 cores, 380/50 – 680/85mm²	0.810

Table 17 Factors to calculate equivalent radius from circular cross section radius. Source: H. Koettnitz, H. Pundt; Berechnung Elektrischer Energieversorgungsnetze; Band I; VEB Deutscher Verlag für Grundstoffindustrie (1968); Page 230.

7.5 How to draw a constant current?

You need to define a course in OpenTrack and use it with an itinerary for the tracks you want to check. In the OpenPowerNet Project-File you need to set the attribute `constantCurrent_A` to the constant current value you want, see the XML snippet below.

```
<Propulsion
constantCurrent_A="2000" This attribute defines the constant current for the engine to 2000A.
You can change the value to whatever reasonable value you need. The following attributes will
be ignored once you set this attribute.
brakeCurrentLimitation="I=f(U)"
engine="electric"
fourQuadrantChopperPhi="none"
regenerativeBrake="maxPower/maxEffort"
supply="DC 600V"
tractiveCurrentLimitation="I=f(U)"
tractiveEffort="maxPower/maxTractEffort"
useAuxPower="true">
  <EfficiencyTable/>
</Propulsion>
```

7.6 How to simulate short circuits?

You need to define a course in OpenTrack and use it with an itinerary for the tracks you want to check. In the OpenPowerNet Project-File you need to set the attribute `shortCircuitEngine` to `true`, see the XML snippet below.

```
<Propulsion
shortCircuitEngine="true" This attribute defines the engine as a short circuit between the
contact wire and the rail. The following attributes will be ignored once you set this
attribute.
brakeCurrentLimitation="I=f(U)"
```

```
engine="electric"
fourQuadrantChopperPhi="none"
regenerativeBrake="maxPower/maxEffort"
supply="DC 600V"
tractiveCurrentLimitation="I=f(U)"
tractiveEffort="maxPower/maxTractEffort"
useAuxPower="true">
  <EfficiencyTable/>
</Propulsion>
```

7.7 How to prevent the consideration of the achieved effort in OpenTrack while using OpenPowerNet?

You need to set the attribute `returnRequestedEffort` to `true`. The requested effort will be returned to OpenTrack but the courses using these engine will be calculated in the network simulation as usually, see the XML snippet below.

```
<Propulsion
returnRequestedEffort="true" This attribute defines to return the requested effort.
brakeCurrentLimitation="I=f(U)"
engine="electric"
fourQuadrantChopperPhi="none"
regenerativeBrake="maxPower/maxEffort"
supply="DC 600V"
tractiveCurrentLimitation="I=f(U)"
tractiveEffort="maxPower/maxTractEffort"
useAuxPower="true">
  <EfficiencyTable/>
</Propulsion>
```

7.8 Where are the XML-Schemas?

The directory path to all XML-Schemas is available via the GUI. Select Schema directory from menu OpenPowerNet. Then a dialog displaying the directory path will open and the directory path is copied to the clipboard.

7.9 Which XML-Schema for which XML-File?

XML-File	XML-Schema
Project-File	OpenPowerNet.xsd
Engine-File	rollingstock.xsd
TypDef-File	TypeDefs.xsd
Switch-File	ADE.xsd

7.10 How to change the working directory?

Working directories need to be defined for OpenPowerNet GUI and also for the analysis tool.

- GUI

The OpenPowerNet working directory needs to be specified within the GUI preferences at `Window > Preferences > OpenPowerNet`.

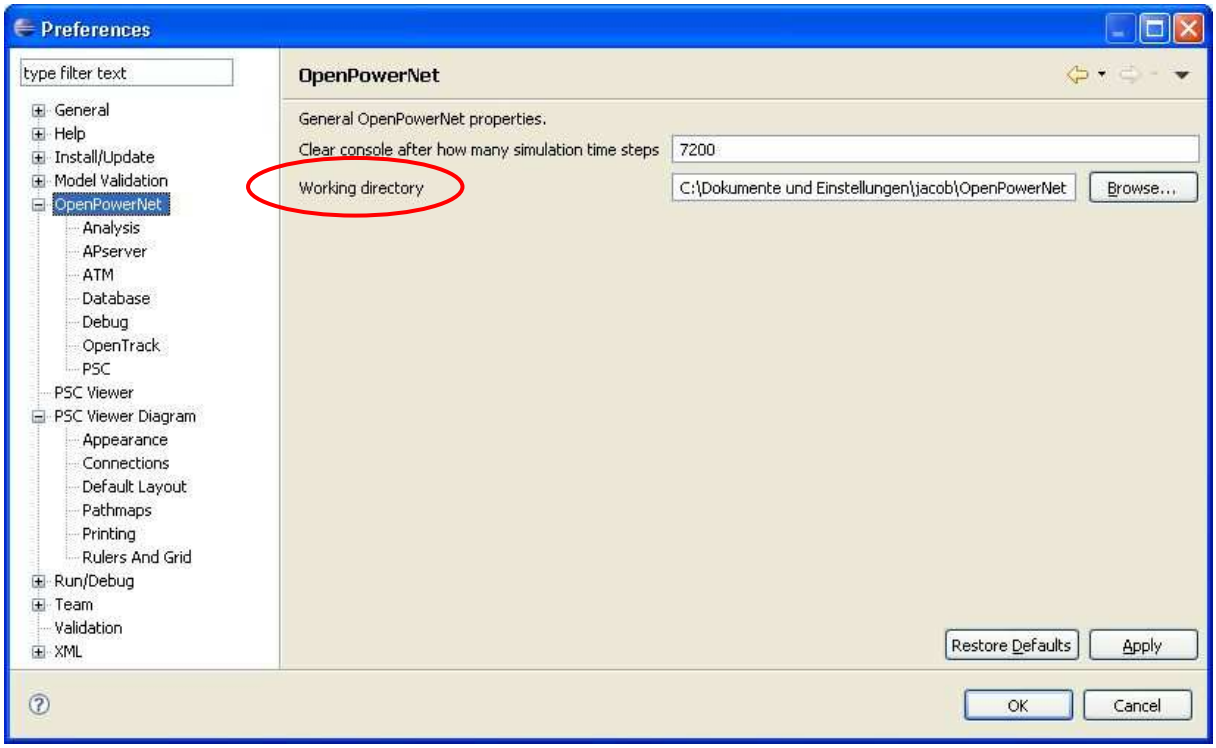


Figure 140 The GUI preferences to specify the working directory.

- Analysis Tool

Within the Analysis Tool the working directory need to be specified via `File > Setup`.

7.11 Any other questions?

For any other question please contact the OpenPowerNet support team via support@openpowernet.de.

END OF DOCUMENT